This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

3 3433 06905539 4

Digitized by Google

Digitized by Google

3-VDA
Institut
Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXVII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
1882.

[*The right of Publication and of Translation is reserved.*]

Digitized by Google

ADVERTISEMENT.

The Institution as a body is not responsible for the facts and opinions advanced in the following pages.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

Digitized by Google

CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

8 *and* 15 *November*, 1881.

PAGE

"Iron Permanent Way." By C. WOOD. (1 plate, 29 woodcuts) . . . 1
Discussion on ditto (17 woodcuts) 27
Correspondence on ditto (35 woodcuts) 68

22 *and* 29 *November*, 1881.

"Forces and Strains of Recoil considered with reference to the Elastic Field Gun-Carriage." By H. J. BUTTER. (3 plates) 122
Discussion on ditto (3 woodcuts) 142
Correspondence on ditto (1 plate, 3 woodcuts) 172

6 *and* 13 *December*, 1881.

Transfer of Associate Members to class of Members 199
Admission of Students 199
Election of Honorary Members, Members, Associate Members, and Associates 200
"The Conservancy of Rivers: the Eastern Midland District of England." By W. H. WHEELER. (1 plate) 201
Appendices: rainfall in the basins of the Witham, Welland, Nene, and Ouse rivers, and at Boston, and its effect in causing floods. 228
"The Conservancy of Rivers: the Valley of the Irwell." By A. JACOB. (1 plate) 233
Discussion on the Conservancy of Rivers. (3 woodcuts) 249
Correspondence on ditto. (1 woodcut) 299

SECT. II.—OTHER SELECTED PAPERS.

"The Weights of Framed Girders and Roofs." By J. H. W. BUCK. (1 woodcut) 331
"Extension of the Dundee Street Tramways." By A. GREIG. (4 woodcuts) 338
The Oxford and District Tramways." By J. BRUNTON. (4 woodcuts) . 345

Digitized by Google

PAGE

"Results of Experiments with Portland Cement gauged with sea and fresh water under different conditions." By H. FAIJA. (1 woodcut) . . . 349

"Steel for Tires and Axles." By B. BAKER 353

"The Current-Meter of Prof. A. R. Harlacher." By R. BLUM. (7 woodcuts) 358

Appendix to ditto 366

"A Study of the Problem of Aerial Navigation, as affected by recent mechanical improvements." By W. POLE. (2 woodcuts) 369

Obituary Notices 395

William Brunton, 395; Frank Fitzjames, 396; John Head, 397; John Furness Tone, 399; James Grey Adamson, 403; William Exall, 405; Alexander Manson Rymer-Jones, 407; John Slate, 408; Thomas Lanfear Tanner, 410; Hamilton Ela Towle, 411; John Hamilton Wicksteed, 413; Edward Bentinck Williams, 415; William Henry Johnstone, Capt. R.E., 415; Angier March Perkins, 417; Edward Antoine Sacré, 419.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Apparatus for Measurement of Base Lines. H. F. REITZ 421

Changes of Length in Wooden Levelling-Staves. H. G. VAN DE SANDE-BAKHUYZEN 421

On the Extension of the Paris Meridian to the Sahara. Hr. PATTENHAUSEN 422

On Graphical Integration as applied to the Statics of the External Forces upon the Simple Beam 424

Self-Recording Indicator of the Elastic Extensions of Loaded Bars. Dr. W. FRÄNKEL 428

Effect of Prolonged Stress upon the Strength and Elasticity of Pine Timber. Prof. R. H. THURSTON 430

Variations in the Limit of Elasticity and in the Modulus of Elasticity of various metals. Prof. BAUSCHINGER 432

Experimental Proofs of some new Formulæ for the Torsion of Prismatic Bodies. Prof. BAUSCHINGER 435

Experiments on the Strength of Wrought Iron and Steel. C. R. ROELKER 437

Determination of the Quality of Iron and Steel. Prof. L. TETMAJER . . 438

Great Structures erected in Italy during the last twenty years. C. CLERICETTI 440

Ventilation and Cooling of Alpine Tunnels. W. PRESSEL 442

Methods of Improving Rivers having a considerable Fall 445

The River Olona Conservancy. L. MAZZOCCHI 447

The Flow of the Sudbury River, Massachusetts, for the years 1875–79. A. FTELEY 448

Blasting under Water. J. DEUTSCH 450

Digitized by Google

PAGE
Hydraulic Canal-Lift at Fontinettes, near St. Omer 451
Contrivance for Working the Needles at the New Overfall at Port-à-l'Anglais Weir. M. Lavollée 453
Rolling Foot-Bridge over the Duquesne Lock at Dieppe. N. Alexandre 454
On the Formation of Sandbanks and Sandhills, and the Construction of Harbours on Sandy Coasts. H. Keller 455
Sluicing Basin at Honfleur. R. Andra 464
On the Measurement of Speed on Railways. Hr. Cörper 466
The Rolling Stock of the St. Gothard Railway. R. Abt 467
On the Working of Local Passenger Traffic on Main Lines. Hr. von Borries 473
The Laying of Gas Mains, and the means of Discovering and Repairing Leaks in them. M. Oppenheim 477
Experiments in the Manufacture of Water-Gas. Dr. Bunte 480
Iron Ore from Amberg, Bavaria. Prof. Bauschinger 483
On a Producer's Classification of Iron and Steel 484
Malleable Cast Iron and the Annealing of Steel. M. Forquignon . . . 492
Theory of the Manganese Blast-Furnace. A. Ledebur 494
Machine-made Muffles for Zinc-Smelting. L. Hiard 496
American Stamps for Gold and Silver Ores. F. Coignet 497
Borings for Coal in the South of France. M. Sarran 499
Timbering Underground Roads in Collieries. H. Daburon 503
Cleaning Coal by an Air Blast. Messrs. Basiaux and Léonard . . . 504
Wire Ropes. A. Garcenot 506
Steel Wire for Ropes. A. Bonnaud 509
Experiments on the Work done by Reaping Machines. Dr. Hartig . . 512
American Milling Methods. A. Hoppin. 513
The Propagation of Magnetic Waves in Soft Iron. H. Whiting . . . 519
Comparative Study of Different qualities of Steel as regards Magnetism and its permanency. R. Pictet 520
New Method of Printing Barometer- and other Curves. H. C. Russell . 521
Units adopted by the Congress of Electricians (Paris, 1881) 522
Action of Cold on the Voltaic Arc. D. Tommasi 523
Principle of the Conservation of Electricity. G. Lippmann 523
On the Yield and Limit of the Operation of the Transmission of Power by Electricity. M. Levy 524
The Measurement of Energy given to Electrical Apparatus. A. Potier . 526
The Efficiency of Electric Motors. Dr. A. D'Arsonval 527
Difference of Potential of the Electric Charges which cover two Metals in Contact. H. Pellat 528
On the Absolute Measurement of Currents by Electrolysis. M. Mascart . 529
Chains of Tubes forming Electric Condensers. Dr. A. Jedlik 529
Duration of Induced Currents. R. Coulon 530
On Dynamo-Machines. Dr. O. Frölich 530
New Kineto-Electric Machines. M. Deblanc 534

Digitized by Google

PAGE
The various systems of Electric Light. E. Hospitalier 534
L. Scharnweber's Electric Lamp 536
The Underground Conducting Network of the German Imperial Telegraph System 537
Application of the Radiophone to Telegraphy. E. Mercadier 537
On the Manufacture of Magnets. G. Trouvé 538
On a Case of Permanent Polarity of Steel opposed to that of the Magnetizing Coil. A. Righi 538
On the Magnetic "After-Effect." F. Auerbach 538
Magnetic Speed-Meter. M. Deprez 540
Electrical Thermometers for observing Temperature at a Distance. M. Lindner 540
Use of the Telephone as a means of Communication during the Training of Infantry. Lieut. von Laffert. 541
On the Future Technical Training of Smelters. Hr. Schlink 542

Index 545

ERRATUM.

Vol. lxvii., p. 149, lines 14 and 15, for "(Colonel, now Sir Andrew, Clarke, K.C.M.G., C.B., Assoc. Inst. C.E.)," read "(Colonel H. Clerk, R.A., F.R.S.)."

Digitized by Google

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1881-82.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

8 November, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

(*Paper No. 1800.*)

"Iron Permanent Way."

By CHARLES WOOD, M. Inst. C.E.

THE Author, in offering the following Paper upon wrought-iron and steel permanent way, proposes to confine himself almost exclusively to two types—longitudinal and transverse sleepers.

On the Continent, particularly in Prussia and in Belgium, both longitudinal and transverse or cross iron sleepers have been in use for many years. The length in miles is about as follows:—1,100 miles of the longitudinal system, equal to 122,000 tons, and 770 miles of the cross-sleeper system, equal to 72,000 tons; or, in round numbers, about 200,000 tons. These figures establish the fact that wrought iron is in great favour with railway engineers in those countries; and year by year its use is greatly extending. As a visitor to many of the ironworks abroad, the Author has found at each works complete plant for their manufacture, whilst at the stations along the lines stacks of iron sleepers are as common as timber ones in this country.

It is hardly necessary to state that on the Continent the Vignoles section of rail is that commonly employed, and until within the last few years the rails were fixed to the timber sleepers with dog spikes. This system has its advantages in first cost and simplicity, and where timber is cheap, and traffic and speeds are light, has met all requirements.

During the last ten or fifteen years, however, traffic has greatly increased; speeds also have been augmented, and the drain upon the forests is beginning seriously to tell upon the cost of wood sleepers.

Digitized by Google

This is important, as will be seen from the Paper upon the durat of timber sleepers by Mr. Funk, of Cologne.[1] Plate 1 shows life of chemically preserved, and of unpreserved or unpic timber sleepers, upon nearly twenty railways, from which i estimated that they last as under:—

	Preserved in Sulphate of Zinc.	Unpreserved.
Oak	19·5 years.	13·6 years.
Red and white deal . . .	12·0 „	6·1 „

It is also proved that the cost of preserving with sulphate of z is one-third less than that of creosote, whilst the life by b methods is equal.

The chief cause of so short a duration of the timber in th countries compared with England is the greater variation in t climate; the winters are more severe, whilst the summers are dr and hotter. The timber is cracked and split by the heat, and wh wet weather sets in rain penetrates to the heart of the sleeper a assists in its destruction. Towards the end of a dry summer it a common thing to find the rails tilting outwards, and from 1 in to 1½ inch out of gauge. In such cases the spikes often stan ¾ inch above the flange of the rail quite loose, and the state the road becomes a source of constant anxiety. These remark show that the present system is defective, which, coupled wit the increased cost of timber, the general demand for faster tra velling and greater safety, is compelling the adoption of som more secure and less costly system. The Author feels justified in saying that this combination of circumstances, in a very large degree, accounts for the progress being made with wrought iron as a material for permanent way. The Prussian Government, however, have declared that, from an economical point of view alone, they are justified in making the change.

The two classes of longitudinal and transverse sleepers have been kept separate, and each system has been arranged, so far as could be ascertained, according to the dates when brought into use. The Author has not described each system in all its details, but those few systems which are most extensively used are more fully explained.

Longitudinal Sleepers.

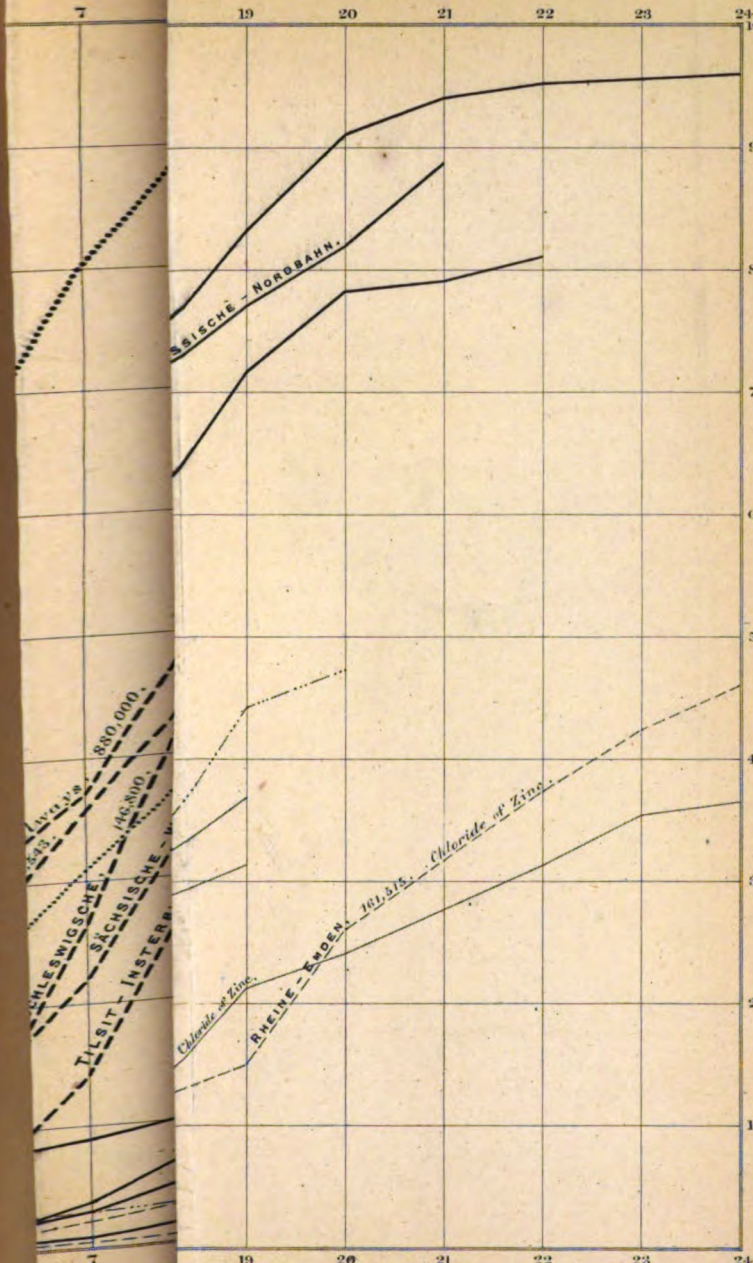
In Papers by Mr. W. Bridges Adams and Mr. P. M. Parsons, read before the Institution, in 1857, there is a full description of the longitudinal systems in use up to that date.[2] These are shown on Figs. 1, 2, 3, 4, and 5.

[1] *Vide* "Organ für die Fortschritte des Eisenbahnwesens." 1880. New Series. Vol. 17, p. 62; also Minutes of Proceedings Inst. C.E., vol. lxii., p. 390.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., pp. 226 and 259.

Digitized by Google

PLATE. 1.

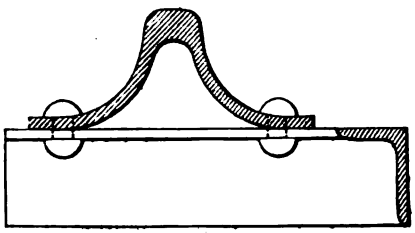


Digitized by Google

Digitized by Google

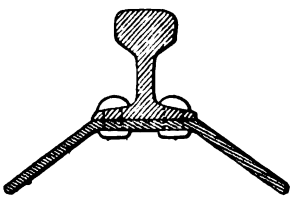
To Mr. Barlow, Past-President Inst. C.E., must be given the credit of having, in 1849, introduced the first wrought-iron longitudinal permanent way. For simplicity of design this has never been surpassed; as a bearer it is equal to any longitudinal system of later introduction. It possessed elements of weakness, however, which stopped its progress, but not until many hundreds of miles had been laid. The Author is indebted to Mr. Thomas E. M. Marsh, M. Inst. C.E., of Bath, for the particulars of several sections of the Barlow permanent way which passed through his hands (Fig. 1). Mr. Marsh states that some of these rails survive in

FIG. 1.



BARLOW'S, 1849.

FIG. 2.

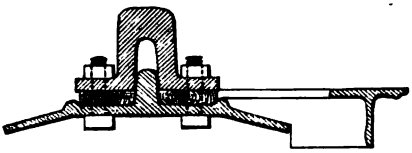


BARLOW'S, 1849.

sidings, but that most of them were adopted as girders in bridge-work after having been worn out as rails. The Author finds also that many miles are in use abroad after thirty years' service. Fig. 2 is also a design by Mr. Barlow about the same date, reference to which is made further on.

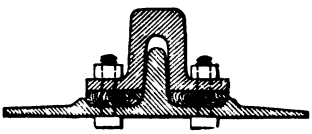
In February 1861, Mr. Francis Fox, M. Inst. C.E., presented a Paper to the Institution upon Iron Permanent Way,[1] in which he gave a description of Mr. Macdonnell's system as laid upon the Bristol and Exeter Railway, now part of the Great Western system. The sleepers are of two forms (Figs. 3 and 4).

FIG. 3.



MACDONNELL'S, 1852.

FIG. 4.



MACDONNELL'S, 1853.

Mr. Fox, in this Paper, describes perhaps the oldest longitudinal sleeper with the rail fixed upon the top. These sleepers, after

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 259.

Digitized by Google

twenty-eight years' service, still carry the whole of the main-line traffic. There exists also a length of 9 or 10 miles of this way upon the Bridport railway, but being of lighter section it has not given so much satisfaction as the portion laid upon the Bristol and Exeter Railway. As will be seen on reference to the illustrations, the sleeper is a continuous longitudinal bearer, upon which the rail is held down by bolts, contact being prevented by the interposition of a packing or liner of pine wood. This wood liner is very beneficial in diminishing the jar upon the bolts, and by forming an elastic medium it assists in keeping the bolts tight.

In a length of roadway tried at the time without the timber, the jar and chatter of the bolts, coupled with the harsh travelling, proved that the system would have been a failure without it, and the wood was soon replaced. Mr. Fox, in the Paper referred to, said that after eight years' experience this system showed a saving of £600 per annum as compared with the timber road laid side by side with it. The rails were more easily changed, the gauge was more correctly preserved, there was a saving in ballast, and less wear and tear upon the rolling-stock through the evenness of the road.

Mr. Hammett, to whom the Author applied as to the condition of the road after so many years' service and whether the above experience could be confirmed, writes:—"The length of line laid is about 14 miles, partly on gravel and partly on clinker ballast. There has always been a difficulty in preventing the sleepers from canting, thus causing the road to get out of gauge. The line was first laid broad guage, but within the last ten years a third rail has been added, making a mixed gauge. The nuts caused trouble by working loose, and the bolt ends had to be burred over to keep the nuts tight. The wrought-iron plates have suffered from considerable corrosion, but, worse than this, they break in pieces, especially at the bolt holes and rail joints, and are very difficult to repair." Mr. Hammett says further, "Please let it be thoroughly understood I am personally at variance with the system, not from prejudice, but from actual experience of its working. It is the most unpleasant line to ride over, difficult to keep in order, costly to maintain, and, as can be well imagined with the speeds of our fast trains, not to be recommended." Such, then, is the experience after twenty-eight years' service, but the fact must not be lost sight of that the traffic, speeds, and rolling-stock, are very different now to what they were when the Paper by Mr. Fox was read, and that what might be

Digitized by Google

considered a good road then would fail under existing circumstances. Nevertheless here is a system of wrought-iron sleepers in use for twenty-eight years, working under heavy traffic, and still serviceable for many years. Comparing the cost per mile of this road as given by Mr. Fox with present prices, it will be found that the same could be put down now for about £700 per mile less than in 1861.

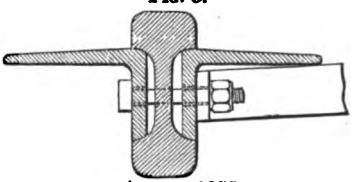
	Cost per Mile 1861. Tons.	£. s. d.	£. s. d.	Cost per Mile 1881. £.	£. s. d.
Rails (iron)	106·85	at 8 2 6 per ton	868 3 0	(steel) at 6 per ton	641 0 0
Bearers .	120	„ 9 3 6 „ „	1,101 0 0	6 „ „	720 0 0
Joint-plates	16¼	„ 9 3 6 „ „	149 1 10	6 „ „	99 0 0
Transoms .	9¾	„ 9 3 6 „ „	90 13 10	6 „ „	58 10 0
Bolts and washers	6¾	„ 9 3 6 „ „	121 10 0	6 „ „	108 0 0
Packing .	..	..	55 0 0		55 0 0
			2,385 8 8		1,681 10 0

Mr. Fox gives the cost per mile of timber road in 1857 as about £2,550.

The Author has described this system at considerable length on account of the close resemblance it bears to some of the same class commonly in use on the Continent, and because the remarks of Mr. Hammett so fully correspond with his own ideas.

About the time that Mr. Macdonnell introduced the sleeper just described, Mr. Bridges Adams brought out his suspended girder rail (Fig. 5), several trial lengths of which were laid in England and in India; but, as far as the Author can learn, they were not satisfactory, and after a few years' service were removed. The chief drawback was in the bolts and nuts, which could not be kept tight, and the difficulty of getting at them; the road was also very harsh to ride over, and liable to cant.

Fig. 5.



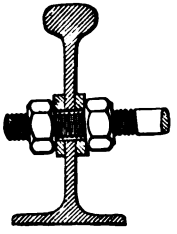
Adams, 1855.

From 1855, when Mr. Adams laid his last trial length, up to 1878 no new wrought-iron permanent way was tried in this country. On the Continent, however, particularly in Prussia and in Belgium, the progress has been continuous. The first experimental length of longitudinal way was laid in 1865 by Mr. Hartwich upon the Prussian Rhenish Railway (Fig. 6). In section it resembles the Vignoles rail, but with a deep web and a rather wide foot. This rested upon the ballast, and when first laid the

Digitized by Google

preservation of the gauge depended entirely upon the ballast. It was soon found, however, that the line could not be kept in order, and the tie-bolts (Fig. 6) had to be employed. Even with this addition the road was not satisfactory; the rails canted outwards, settled bodily down in the ballast, and were a source of constant expense. The difficulty in packing up and retaining such a deep rail in gauge and tilt will be readily seen. The system was continued several years upon the main lines, and may yet be seen in sidings in that district. It is spoken of as being in first cost very cheap, and for simplicity of parts it may rank with Barlow's, being however deficient as a bearer upon the ballast, but much stronger at the joints compared with the latter. In 1870 there were 112 miles laid on this system, but in 1880 only 10 miles were in use on main lines and about 30 miles in sidings.

Fig. 6.

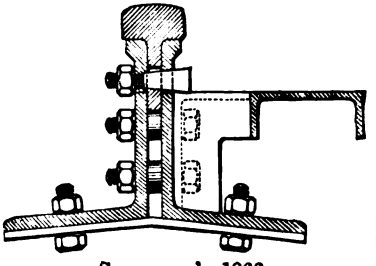


Hartwich's, 1865.

Following Hartwich, Scheffler in 1866 adopted a tripartite system for the Brunswick Railway (Fig. 7).

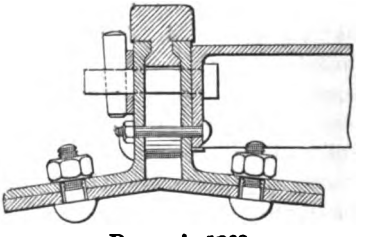
Several miles of this system are open, but the rail is weak,

Fig. 7.



Scheffler's, 1866.

Fig. 8.



Daelen's, 1868.

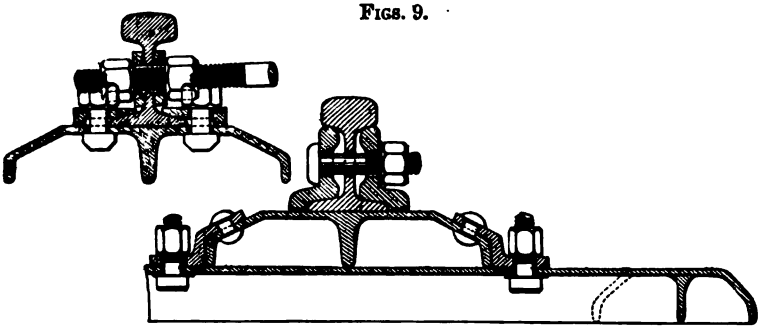
and causes trouble by lifting and breaking. To meet the difficulty Mr. Daelen introduced a modification in 1868 (Fig. 8). The superior strength of this rail, held tight as it is by the clip-shaped bearers well bolted together, produced a firm road. It remains in use upon the Kreienzen and Holzminden Railway, and is said to be a great improvement on Scheffler's, and to give fair satisfaction; but the Author learns that in both these sections, the great cost, the constant attention required to keep the bolts tight, and the difficulty of adapting them effectually to curves, put a stop to their further employment. In design the two last systems may

Digitized by Google

be classed with Adams' suspended girder-rail, the chief difference being that the vertical webs are placed above the horizontal bearer instead of below, so that the bolts and transoms can more readily be got at.

In 1867 Mr. Hilf laid a trial length of his longitudinal system (Figs. 9) upon the Ems and Wiesbaden Railway. Its success rapidly led to further applications, and year by year it has been extended in Germany and Belgium, until a length of about 900 miles has been laid, amounting to not far short of 100,000 tons of sleepers (rails not included). Hilf's longitudinal sleeper some-

FIGS. 9.



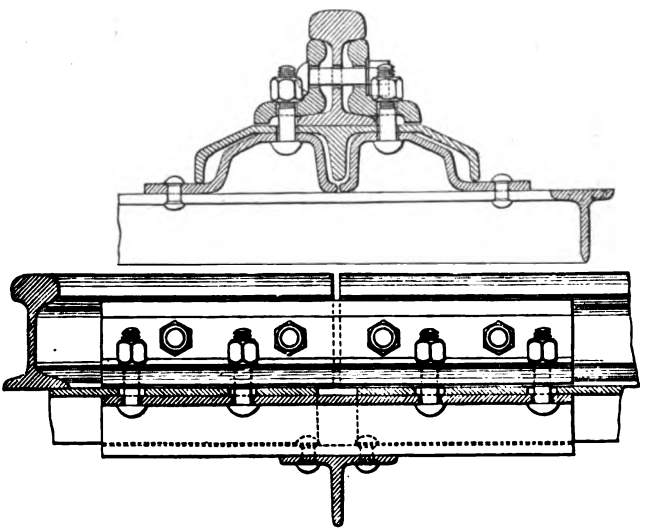
HILF'S, 1867.

what resembles Barlow's (Fig. 2), but it has a central web. In the earlier sections the rail was of iron 4½ inches high, and weighed only 54 lbs. per yard. It was argued that as the sleeper and the rail were firmly bolted together they would support each other, and that a light section of rail would suffice. The middle web under the sleeper not only materially stiffened it, but gave it a grip upon the ballast. In practice, however, the rails proved far too light and too low. The flanges of the wheels came in contact with the gauge rods, so that in all the later sections the rails have been increased gradually in weight to 65 lbs. per yard, and in height to 4⅞ inches. This additional strength in the rail has materially improved the road, and is being adopted wherever the system is employed. The rails and sleepers are made of nearly the same length, the sleeper being a little shorter than the rail. The fish-plates now employed are of great strength, having angles or brackets on the bottom. These angles fish the sleepers as well as the rails, and the joint of the rails is said to be equal to 80 per cent. of the whole strength of the rail. With these improvements the system gives satisfaction, and in Prussia has many advocates. One of the chief objections to its

Digitized by Google

use is the difficulty of preventing the bolts and nuts from working loose and chattering. From personal observation the Author thinks the wood liner employed in Macdonnell's way is superior to Hilf's in this respect. Where the traffic is frequent this loosening of the bolts and nuts becomes serious. The threads of the gauge rods cut down upon the web of the rail, the nuts work slack, and the rails and sleepers cant outwards. To meet this, transoms have been employed (Fig. 9) of the same section as the sleeper, curved at the ends to give the tilt to the rail. These are placed immediately under the joints of the rail and sleeper. But another evil has been produced. In consequence of the extra bearing obtained from the wide transom, and of its being considerably deeper in the ballast, the sleeper rests upon a firmer bed, and the joints become so rigid that the way sinks between the transoms, thus forming a series of waves. When a thaw takes place after frost the rails sink in the middle from $\frac{3}{8}$ to $\frac{1}{2}$ inch; the ballast at such times is often frozen hard under the transoms, and is quite loose under the longitudinals. To meet the difficulty tee-iron transoms have been employed on the Berlin Nordhausen Railway in place of the sleeper section (Fig. 10), so as to reduce the resistance on the

FIGS. 10.



HILF'S.

ballast, and with a beneficial effect; but it has not proved sufficient. On the lengths laid in the autumn of 1880 upon the Moselle

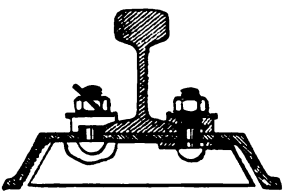
Digitized by Google

Railway the sleepers were left with a space of about 3½ inches between their ends, to allow of a strong angle-iron transom coming up immediately under the flange of the rail. The transom here lies at the same level in the ballast as the longitudinals, and is equally affected by changes of temperature. This plan, with the strong rails and fish-plates alluded to, is said to be a great improvement.

Another difficulty is the impossibility of bending such a section to the curves, and the sleepers have therefore to be laid in a series of straight lengths with the rails in a curve on their top; consequently the sleepers have to be differentially punched to allow the bolts and clip-plates to catch the foot of the rail, and any great variation in the radius of the curve necessitates different punching. No less than eight different templates are required for this purpose. At certain spots along the line where there are curves it is necessary to keep a stock of thirty different kinds of sleepers to meet all emergencies, and it will be therefore seen what serious consequences may arise from a breakdown should not the right section be at hand; whilst skilled men with cranes and tools only can be employed. Where curves are frequent the old system of cross-sleeper is often retained, and at points and crossings Hilf employs a cross sleeper of similar section without the middle web. To every yard of railway laid on this system twenty-two separate pieces are required, not including rails.

The middle web has sometimes been objected to on the ground that it splits up and divides the ballast to an injurious extent, that it forms a gutter in which water collects, and that it greatly adds to the difficulty in rolling. A sleeper intended to overcome these objections has been designed by the engineers of the Prussian Rhenish Railway Company (Fig. 11). It is a plain trough, free from ribs, and is said to lie more steadily upon the ballast than Hilf's; the rail is held upon the sleeper in a similar way. The fish-plates are of great strength, but are not bolted to the sleepers like Hilf's later section. The sleepers are not fished, and the end of the rail overlaps the sleepers about 18 inches. The rails are 30 feet long, 5⅛ inches high, and weigh 57 lbs. per yard. The gauge-rods are about 10 feet apart, and are similar to those employed by Hilf; they are open to the same objections through the clattering of the nuts and the cutting of the threads upon the web of the rail. There are no transoms,

FIG. 11.



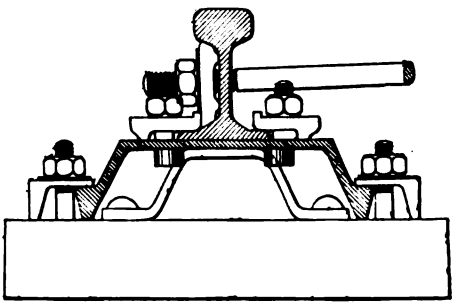
PRUSSIAN-RHENISH.

Digitized by Google

and the line is free from the wave-like settlement to which Hilf's system is liable. The gauge-rods are not, however, effectual in preserving the proper tilt, and the rails after a time cant outwards. All the nuts are furnished with split washers, one side of which turns up so as to prevent the nuts from working round, but it does not stop the chattering. The sleeper, through dispensing with the middle web and the transoms, is about 15 lbs. lighter per lineal yard of railway than Hilf's; but in all other respects the same remarks apply with regard to differential punching for curves. About 110 miles of this system are open.

In 1876 Hohenegger laid a few miles upon the North Western Railway of Austria, the chief point of which is the greater depth of the sides, and a different mode of fastening upon the transoms (Fig. 12).

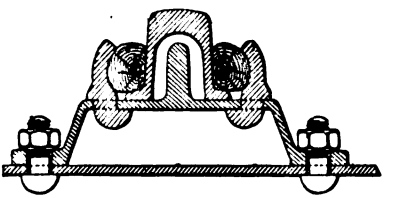
FIG. 12.



HOHENEGGER'S, 1876.

About the same date Mr. Heusinger von Waldegg brought out a new fastening (Fig. 13). The only bolts used in this are for the

FIG. 13.



HEUSINGER VON WALDEGG'S, 1876.

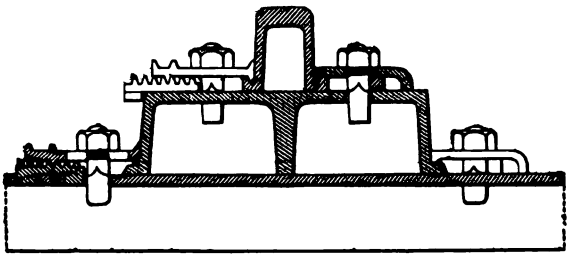
fish-plates and transoms, the rails being held by wood keys and loose clips. Bridge-rails are preferably employed, and are said to answer well, particularly in steel. The rails lie in a bent form upon the top of the sleeper in curves, as in all the longitudinal

Digitized by Google

systems before described, the gauge being adjusted by putting in thicker wood keys on one side or the other. The rails are easily taken out, there being no bolts to put up under the sleepers. Several small trial lengths have been laid in Germany.

Mr. Kirsch, Engineer to the Grand Central Railway of Belgium, introduced a form of sleeper in section somewhat resembling the Hilf trough, but deeper in the webs, and more expensive to roll (Fig. 14.)

FIG. 14.

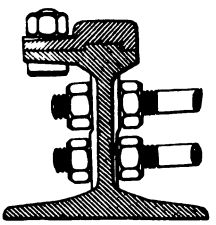


KIRSCH'S.

The bridge-rail has its edges turned up at the sides, into which toothed racks fit; these racks adjust the rails on the top of the sleeper to the curves; but it is a complicated and expensive permanent way, and, from the number of loose pieces, is one to be avoided.

A more simple scheme is that by Dr. Winkler (Fig. 15).[1] The design resembles Hartwich's deep rail tried on the Rhenish Railway (Fig. 6); but having the head of the rail in parts is objectionable, and, judging from experience with others of this class, could not be kept in place.

FIG. 15.



DR. WINKLER'S.

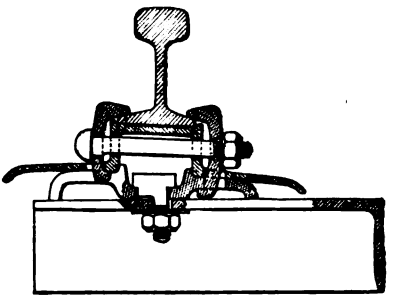
The only other system which has achieved success or notoriety is that of Haarmann. When this system was first tried the rails were too light, but they so far succeeded that the Prussian Government gave an extensive order, which was to comprise certain improvements made by Mr. J. W. Schwedler, of Berlin (Fig. 16). The sleeper is 12½ inches wide, and has a raised box in the middle, with a groove upon the top to receive the foot of the rail. The rail is held by two cramp irons, kept in position by a bolt passing through both cramp irons and the raised box part of the sleeper. The wings of the sleeper are thin and elastic. The

[1] *Vide* "The Engineer," 19th December, 1880.

Digitized by Google

tilt is obtained by a malleable iron saddle resting upon a straight angle-iron transom (Fig. 16). The sleepers are fished with a malleable iron plate, and held together with eight bolts. The rail joints

FIG. 16.

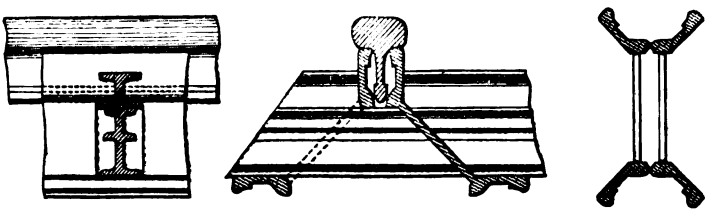


HAARMANN'S.

overlap the sleepers about 12 inches. The rail is 5 inches high, and, like most of the systems last described, strongly fished, having bracket fish-plates with four bolts. In addition to the transoms, there are rods to assist in keeping the road in gauge. The mode of holding the rail is novel, perhaps more simple than Hilf's system, and the form is said to give flexibility and easiness in travelling. The joints of the sleepers remain firm in use; the sleepers lie upon the surface of the ballast, and the transoms being shallow have not the effect of causing unequal settlement. One serious drawback to this plan is in the curves, as both rails and sleepers must be bent—a troublesome and expensive operation. Practically the elevation of the head of the rail being so much above the sleepers, makes them liable to cant outwards. The fastenings for the rails appear to be at the expense of stability, but the system seems to afford satisfaction.

The last longitudinal system to be noticed is that of De Serres

FIGS. 17.



DE SERRES AND BATTIG'S.

and Battig (Figs. 17), which, when first brought out, attracted considerable notice from the simplicity of its parts. Several trial

Digitized by Google

lengths have been laid in Belgium, Germany, and Holland. The system is one of the tripartite type; the rail, having a large head with a short thin web, is held by the nipping action of the sleeper, which is tightest when the weight is upon it. The rail was originally held down with two pins only. The sleepers are in two parts, and break joint one with the other; they are kept in gauge by strong tie-bars, having notches upon their upper side, which hold the top of the sleepers together, the bottoms being free to expand outwards, so that the heavier the weight the more the rail is nipped. The tie-bars are 4⅜ inches deep, and weigh 10½ lbs. each; the intermediate bevel-ended keys are of the same section, placed 2 feet apart, and assist in holding the top of the sleepers together. The large holes for the reception of these tie-bars and keys weaken the sleepers, and necessitate a strong foot, and the weight of metal is consequently not well distributed. One of the chief difficulties has been in the manufacture; it was almost impossible to roll both the rails and the sleepers without some twist of the webs; consequently, when the road was being laid, the parts fitted so badly that both rails and sleepers had to be returned to the works to be straightened. Two of the trial lengths, in consequence of the lifting and constant breaking of the rails, have been taken up and are not likely to be tried again.

Transverse Sleepers.

Thus far the Author has confined himself exclusively to longitudinal sleepers; he will now notice those on the cross or transverse system.

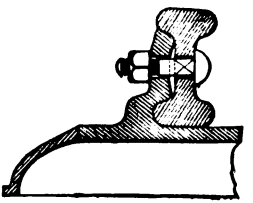
Wrought-iron cross sleepers were first employed by Mr. Le Crenier, in 1860, who used a light channel iron, with the flanges downwards. They were 7 feet 10 inches long by 10 inches wide, and weighed only 52 lbs. each. The rails were of the Vignoles section, placed directly upon the top, and held down by fixed brackets bolted to the sleeper.

In 1862 the Couillet Forge Company in Belgium tried some cross sleepers of girder section, 7 inches wide, with shallow flanges, and 8 feet long, weighing 101 lbs. each. These were laid flat upon the ballast, the Vignoles rail being bolted upon them, bedded upon a cushion of hard wood. Both these systems were wanting in vertical stiffness, and the fastenings were deficient; they were, however, in use up to a recent date, but only upon roads where the traffic was light. They were laid first in Belgium and afterwards in France, Portugal, and Holland. Besides these, some were laid upon the Valencia and Tarragona Railway, but they

Digitized by Google

proved too light, and did not give satisfaction. In 1863 Mr. W. Barningham tried a short length as an experiment upon the Great Eastern Railway. The sleepers were of a circular trough shape, with a single wrought-iron jaw welded upon the top at each end (Fig. 18). They were made to fit the double-headed rails in use upon that line. Holes were punched in the rails at equal distances, and a single bolt through the rail and jaw formed the fastening. The difficulty and almost impossibility of welding jaws upon long sleepers, so as to keep them accurate to tilt and gauge with a proper bed for the rail, is obvious. The cost of welding and adjusting would prohibit their use in practice, whilst a single bolt under such circumstances would never hold tight.

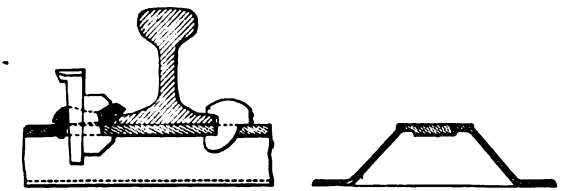
FIG. 18.



BARNINGHAM'S, 1863.

In 1864 Mr. Vautherin introduced his now well-known cross sleeper upon the Lyons Railway. The Northern of France Railway followed, and other French lines also laid several miles of this system. On the first-mentioned railway the sleepers were 9 inches wide, while on the latter they were 10½ inches wide, the extra width being added upon the horizontal foot (Figs. 19). The sleepers

FIGS. 19.



VAUTHERIN'S, 1864.

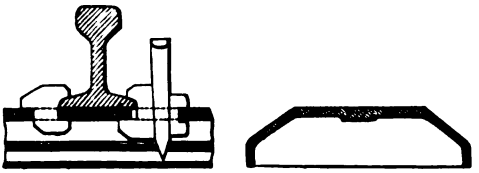
were ⅜ inch thick in the centre of the top, whilst the inclined sides being $\frac{3}{16}$ inch thick, and weighed 64 lbs. each; the rails were held down by keys and cotters. Like all the first sleepers rolled upon this system they were too light, and gave a great deal of trouble; ultimately they had to be taken up. A similar result was experienced in Spain, which had the effect of prejudicing the engineer against any further trial of wrought-iron sleepers. In 1868 ten thousand of these sleepers were laid in Belgium of different lengths, with an idea to their further extension; but although these were not successful, it was seen that had they been stronger, and the fastenings been improved, they would ultimately have been

Digitized by Google

economical. It was observed that the line was kept better to gauge and tilt, and the running was easier and safer than upon the oak sleepers; the defect being in their weakness, producing fracture, and the working loose of the fastenings. Much trouble is caused by the keys working out, and upon the lines where these fastenings are still in use it is necessary for a platelayer to walk three times a day over the length of line under his charge to examine the fastenings. The result of the constant driving of these keys has been to split the sleepers through the key-holes. Of the original ten thousand a few only remain in the main roads; the rest have chiefly been removed to sidings or have been broken up. Those now being laid in Belgium are of similar design, but much stronger; they weigh 90 lbs. each, and are 6 feet 9 inches long, the rail being fixed with gibs and cotters; seven sleepers are laid to each rail of 20 feet. At one time sleepers of two different lengths and widths were employed, but those lately ordered are all of one size. The last-mentioned sections are ½ inch thick through the crown, with a proportionate strengthening of the horizontal foot and inclined sides. In Prussia, in 1873, about 14 miles of this same type were tried; they were also in two lengths, one half being 8 feet 3 inches long, and the other 7 feet 3 inches. After eight years' use they have stood well, only one sleeper in six hundred and fifty having broken; the chief trouble has been with the fastenings.

One of the latest forms of cross sleeper has been laid on the Bergisch-Märkisch Railway (Figs. 20). In shape it is like Hilf's

FIGS. 20.



BERGISCH-MÄRKISCH.

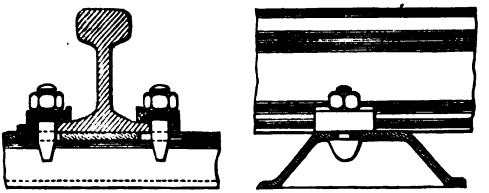
sleeper, without the middle web; they are 7 feet long by 9¼ inches wide, and weigh 98 lbs. These have stood well. The fastenings are of the Vautherin type, but being made heavier in steel and carefully fitted, they do not give so much trouble as those before mentioned. On the same line there are also one hundred thousand wrought-iron sleepers, of the same section, but of heavier construction 8 feet long by 12 inches wide by ½ inch thick, weighing 126 lbs. each, which are giving great satisfaction. The cost of the steel

Digitized by Google

fastenings is about £20 per ton, and the sleepers come to about £6 10*s.* per ton at the works. The cotters and keys are made of four different patterns, so as to set the rails wider to gauge on curves; but on some of the lines employing the cross sleeper this has been found unnecessary, one gauge only being now in use. The sleepers on this railway have their ends turned down, so as to prevent end-shifting, and the ballast working out. Sleepers without any horizontal foot are said to lie much better upon the ballast, the edges sink and compress the ballast inside the sleeper, so that the crown only carries the weight. Mr. Grüttefien states "that the horizontal foot cannot be justified in point of construction, as it often strains the sleeper through resting upon hard pieces in the ballast, and that the sleeper should rest only upon the 'crown.'"

The Prussian Rhenish Railway Company employ a cross sleeper of rolled iron, somewhat similar to the Vautherin section, but with a narrow foot (Figs. 21). The rail is held by bolts and clips, the

FIGS. 21.



PRUSSIAN RHENISH.

bolts have tee heads, which pass through and turn round in the sleeper; and the clips, which are also of rolled iron, are so constructed that they partly drop into the holes made for the bolts, thus preventing the bolts from shifting or turning round; they also take part of the outward thrust of the rail. The fastening looks simple, but the nuts work loose. The clips are of different widths, so as to widen the gauge when required. These sleepers, with the fastenings, weigh 77 lbs. each. They are 7 feet 4 inches long by $\frac{3}{8}$ inch thick on the crown, and a piece of angle-iron is riveted in to fill up the end of each sleeper.

Both the last-mentioned railway companies are now using steel sleepers so soft that the ends are bent over in a cold state.

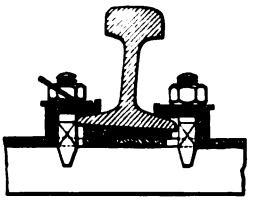
All the cross-sleeper systems thus far mentioned obtain the tilt for the rail by curving the sleeper, the rail resting directly upon it.

The Dutch Rhenish Railway Company has adopted a similar section to that last described; the sleepers are of rolled iron

Digitized by Google

9 inches wide by $\frac{3}{8}$ inch thick in the crown, and weigh, with the fastenings, 112½ lbs. each. The tilt is produced by placing a bevelled plate between the rail and the sleeper (Fig. 22). In other respects the clips and fastenings are similar to those used with the cross sleepers of the Prussian Rhenish Railway. The tilt-plates are notched so as to drop over the bolts. They seem to the Author to be superfluous, when the tilt can be obtained so easily by curving the sleeper. On the other hand, Mr. Wright, the Resident Engineer of the railway at Utrecht, thinks that a perfectly straight sleeper would counterbalance the disadvantages of a loose plate; but the Author is of opinion that it must cause chattering of parts. These sleepers have also the ends closed with angle-iron riveted on. The contract price, including all the fastenings and tilt-plates, was 6*s.* 8*d.* each sleeper delivered in Amsterdam. Baltic oak sleepers cost 5*s.* each delivered at the same place, and last on an average only ten years. Altogether about half a million iron sleepers are laid in Holland.

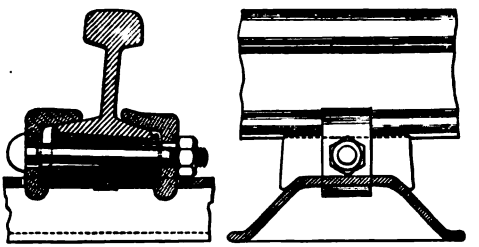
FIG. 22.



DUTCH RHENISH.

Mr. Haarmann has also introduced upon the Cologne-Minden Railway a cross sleeper, and, in order to get in the cramp fastenings employed upon his longitudinal system, he has inserted upon the top of the sleeper, immediately under the rail, a bevelled cast-iron

FIGS. 23.



HAARMANN'S.

block (Figs. 23). The cramp-irons are made of malleable cast iron (*fluss-eisen*). The cast-iron block is hollow, and has a tongue which fits tightly into a hole in the top of the sleeper to keep it from shifting. The total weight of the sleeper is 119 lbs., including the fastenings; it is 7 feet 7 inches long by 10 inches wide, and $\frac{3}{8}$ inch thick at the crown. The fastenings are said to be

Digitized by Google

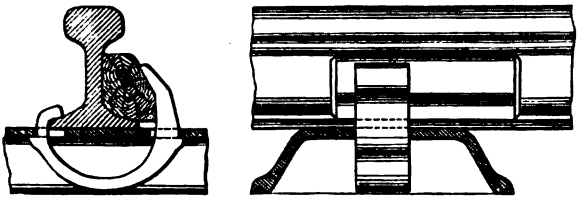
better than those previously noticed, but the Author thinks that simplicity and fewness of parts has been abandoned to arrive at this; also that all depends upon this one bolt, and that should either cramp or bolt break there would be nothing to keep the rail in place. Mr. Wright, who has some of these on trial, says that the only benefit is that the sleeper can be buried in the ballast. Mr. Haarmann's cross sleeper, like nearly all those previously mentioned, has the ends closed by a piece of angle-iron riveted in. It is urged by engineers on the Continent that this boxing in is to prevent the sleepers shifting endways, and that they then oppose the same resistance as timber sleepers; also that it helps to keep the ballast intact, and prevents it from escaping at the ends. The Author has examined many different systems, and has seen most of those in use, but has failed to discover the utility of this extra cost and weight. He feels confident that if the extra outlay were employed in widening and lengthening the sleepers better results would be obtained. It is certain that on straight lines or on easy curves there can be no tendency to shift endways, and the extra cost in this respect would be wasted. The working of the ballast out of the end of the sleepers has arisen from the employment of sleepers too short and of too light a section. When a train passes over the light cross sleepers of the Vautherin type, the sleepers spring considerably immediately under the rail, the reason being that they are not sufficiently strong to distribute the load over the ballast, which consequently is driven away, and the sleepers lie hollow under the rail, producing a loose and disturbed appearance in the ballast. The ends have been put in with an idea to check this disturbance, but the Author is convinced that no benefit has been thereby derived.

In the Author's system, as laid upon the North Eastern Railway at Middlesbrough (Figs. 24), the sleepers are 8 feet 6 inches long, by 11 inches wide, by $\frac{3}{8}$ inch thick throughout; the sides are inclined outwards, and are designed to hold and keep the ballast intact as much as possible. The tilt is given by curving the sleeper as in the Vautherin, and other systems. It will be noticed that should one or even two keys drop out, which is improbable, the clips remain in their places, and the rail is still held to gauge, and firm against outward thrust. For the ordinary gauge the clips are $2\frac{1}{4}$ inches wide by $\frac{1}{2}$ inch thick, so that before it could get out of gauge the flange of the rail would have to shear off this thickness of iron the full width of the clip, which is practically impossible. This fastening for the rail is simple, comprising a single piece of iron bent into a horseshoe shape, one

Digitized by Google

end of which is hooked to hold the flange of the rail, whilst the other is carried up sufficiently high to form a jaw to take in a wood key as in an ordinary railway-chair. The chairs (called "clip-

FIGS. 24.



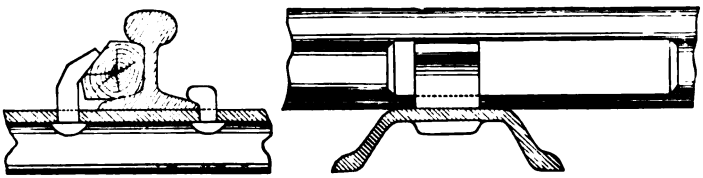
WOOD'S, 1878.

chairs") are of wrought iron rolled in bars the width of the clip required, the irregular thickness of which is arrived at by the cutting away of one of the rolls. These bars are afterwards sheared off into proper lengths, and then bent into the required shape in a press over a mandril by machinery designed for the purpose. The clip-chair, being of a horseshoe or bow shape, is elastic, and when a compressed wood key is driven in tight between it and the rail with a platelayer's heavy hammer, the jaw being forced outwards, wedges the bow under the sleeper, and the spring thus produced keeps a constant pressure upon the key; so much is this the case, that the keys remain tight in all weathers. The iron jaw follows the expansion and contraction of the wood key, and so effectual has this proved, that on the lengths laid at Middlesbrough, after three severe winters and three summers, the keys have remained tight in their places, with one or two exceptions. These sleepers are laid upon a part of the road carrying perhaps the heaviest traffic in the kingdom. The first rails have worn out and new steel ones have been substituted, the same clips and wood keys being used again. The traffic over these sleepers during the past three years has been upwards of 60,000,000 tons. The Author thinks no other system can show such an experience, which is the more remarkable considering the heavy traffic; and the result has been the same wherever they have been laid. Whether the sleepers themselves are strong enough to support the enormous traffic at Middlesbrough time alone can decide; so far they have carried as much traffic in the time mentioned as any of the continental systems laid twelve years ago. If any alteration were made, it should be in strengthening the foot of the inclined

Digitized by Google

sides; but so far the fastenings have proved satisfactory. For narrow gauge (say less than 3 feet), portable or light railways, such as are used in mines, quarries, and sugar plantations, for public works for India, for metre gauge, &c., 16- to 25- or 30-lb. steel rails are used, and fixed clips formed in the manner shown by Figs. 25 being preferred, as for such light rails loose pieces are objectionable; but for rails above these sizes the loose clips are best.

FIGS. 25.

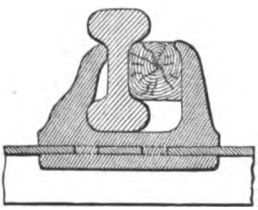


WOOD'S, 1878.

At the Düsseldorf meeting of the Iron and Steel Institute in 1880, Mr. E. Martin introduced a sleeper of wrought iron with a cast-iron chair cast upon it. Holes are punched in the sleeper, through which the metal flows and unites in a plate underneath. This sleeper was, the Author is informed, originally invented by the Rev. Osborne Reynolds in 1848 (Fig. 26).[1]

For a double-headed rail when once in place no doubt this would do fairly well, but it is impossible to renew a single sleeper without removing both rails; and the difficulty in manufacture is such that it is almost impossible to keep the chairs either to tilt or gauge. Again, the extra cost of moulding, with the liability to make a bad casting at either end of the sleeper, will so much add to the cost as practically to keep them out of the market.

FIG. 26.



REYNOLD'S, 1854.

Mr. Livesey's wrought-iron sleeper (Fig. 27), now being introduced on some colonial metre-gauge railways, is made out of sheet iron $\frac{3}{16}$ inch thick, heated and compressed in dies to shape; each clip has two rivets or eight rivets to each sleeper,

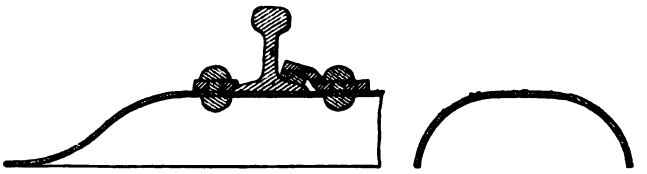
[1] Specification of Lewis Dunbar Brodie Gordon. Railways. A.D. 1848. No. 12,149. London, 1857.

Digitized by Google

and the iron keys are corrugated to prevent them being jarred out.

Mr. F. W. Webb, M. Inst. C.E., of Crewe, has lately brought out a wrought-iron transverse sleeper for taking in the bull-headed rail

FIGS. 27.



LIVESEY'S.

of the London and North-Western Railway; the chairs are of steel, riveted on to the sleeper.

Next in importance to the construction of the sleepers is the ballast upon which they lie. Referring to the time when the Barlow system was in common use, Mr. T. E. Marsh says, "It was found that the best ballast was broken stone or furnace slag, with a top dressing of gravel, and thorough drainage." On the Great Western Railway between Bristol and Exeter, Mr. T. Hammett, who has charge of the Macdonnell way before alluded to, states "that the ballast employed is part gravel and part clinker;" whilst Mr. Francis Fox, M. Inst. C.E., who originally laid this way, says that broken stone was found best. In Prussia the general practice is to use a top dressing of moderately rough broken stone; shingle or gravel is not liked, as it rolls away from under the sleepers. Mr. von Grüttefien says, "The Hilf system lies all the better, and its cost of maintenance is less, the rougher the stone-ballast up to a certain degree." Ashes and clinker ballast are condemned.

In Belgium until recently the practice was to prepare a rough bed of large stones, with a dressing of broken stones from 5 to 6 inches deep, or of sifted gravel 1½ inch in diameter, and about the same depth. Clean crushed slag or stone can be had at about 1*s.* 6*d.* per cubic yard at furnaces or quarries, and 1 cubic yard will lay about 4 square yards 9 inches thick. The present custom is to put a single bed of from 15 to 18 inches of broken stone or slag of about 2 inches diameter, upon which the iron sleepers, when once properly bedded, give little trouble to keep in order. Stone ballast is less costly to maintain than the ordinary ballast used with wooden sleepers. In the neighbourhood of blast-furnaces slag has come commonly into use, broken down into 2-inch pieces.

Digitized by Google

A few years ago granulated slag in large quantities was tried as a top dressing, but the dust produced by the traffic in dry weather got into the axles, and caused so much damage that it led to its disuse. Slag is employed now only in a small broken state, and is practically free from dust. The Northern of France Company has cleared away from the neighbourhood of Liége a large slag mountain for ballast, and is now at work upon a second.

In Holland, Mr. Robert Wright says, "broken hill gravel is largely used; river gravel was found too round, and could not be kept together; blast furnace slag broken small is also employed, as well as broken stones; these keep together, and form a capital dry bed." There cannot be a doubt, therefore, that one of the best ballasts for wrought-iron sleepers is small broken stones or slag, failing which small gravel or even coarse sand; but it is essential that thorough good drainage should be secured, to prevent suction into the hollow of the sleeper.

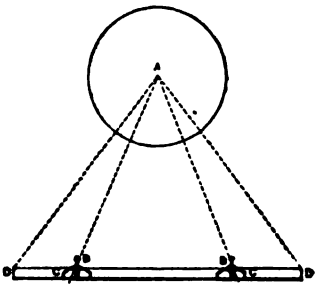
With regard to corrosion of wrought iron when thus employed, Mr. Marsh states that in all his experience with the Barlow rail the corrosion was not worth taking notice of; in fact, he says that when the rails were worn out as rails they were used in bridge work. The Author saw two cargoes of old Barlow rails landed at Middlesbrough from Spain, and after twenty years' use there was not a single rail which could be said to be injuriously affected by rust. Mr. Hammett observes that the Macdonnell way under his charge has suffered considerably from corrosion, but the Author is of opinion that the rust has been induced by the clinker ballast—an effect which engineers engaged upon iron works are well acquainted with. But this wrought-iron way has been in use nearly thirty years. In Germany, Mr. Grüttefien remarks that the effect of oxidation is so slight that it is unnecessary to make any provision against it, and the Author can confirm this from his own observations. It may be taken as a fact that upon a moderately well-drained railway under traffic practically no corrosion takes place; also that rails laid by the side of a railway in a few months become corroded, whilst those in use are not affected. The same phenomenon takes place in the iron sleepers, and there can be little doubt but that so far as rust is concerned they will last from forty to fifty years, and will then be worth as old iron half the value of new sleepers.

From the foregoing it seems that wrought-iron sleepers are widely used upon the Continent; and although the Hilf and other longitudinal sleepers have their advocates, and large orders for them are yearly given, still the cross sleeper during the last few years has been and is materially gaining ground. In Belgium and

Digitized by Google

Holland the longitudinal system has been altogether discarded in favour of the cross sleeper, and it appears to be the general opinion that the latter will eventually be the only one used. With all the longitudinal systems the difficulties of having so many sizes for the curves, the canting of the sleepers, the unequal settlement in the ballast, the difficulty in shifting the line sideways, and the general want of stability and bearing surface upon the ballast, are, in the Author's opinion, sufficient to prevent any further extension, especially as few, if any, of these objections can be sustained against the cross sleeper. It will be seen (Fig. 28) how much

FIG. 28.



more stable a road must be when laid upon a cross sleeper than upon the longitudinal. Thus supposing A to be the centre of a locomotive boiler, the point of upsetting resistance in the longitudinal system would be at BB, which, acting upon the outside of the sleeper at CC, will show the difficulty there is in keeping these from canting; whilst, on the other hand, with the cross sleepers the point of resistance is removed to DD, or an angle nearly double.

In climates subject to heavy rainfall scouring becomes serious, particularly upon new work badly drained. Take an incline upon a curve with longitudinal sleepers, and the water coming down on the inside of the road, the ballast will be washed away from beneath the sleepers, whilst the cross sleeper not only gives a check to the water, but allows it to pass freely out, preserving the ballast intact, and at the same time distributing the load over nearly double the area of ballast.

Why the cross-sleeper system did not find earlier advocates is not difficult to see, considering the very light sections originally laid and the miserable results which followed. Many of these sleepers were only from 40 to 50 lbs. weight for a 4 feet 8½ inches gauge, whereas at the present time sleepers of 1 cwt. each are not con-

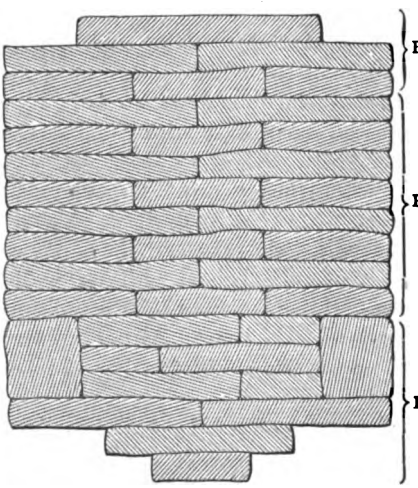
Digitized by Google

sidered too heavy, and the only complaint against them is the chattering and loosening of the fastenings.

One of the chief things to be looked for in an iron sleeper is simplicity of parts, particularly when they have to be sent abroad; something is wanted which cannot be put together wrong, and which requires little judgment on the part of the workmen to keep right. The Author has pointed out over and over again the trouble that multiplicity of parts involves, and the constant attention required to keep them in order. His own system upon the North-Eastern Railway seems to have met these requirements.

Wrought-iron sleepers should be made of best-best iron, or iron capable of standing a strain of at least 22 tons to the inch. If made of Bessemer steel they will be more serviceable. The sleepers should be straightened when hot as they come from the rolls, the holes should all be punched in a machine simultaneously, and a carefully-prepared gauge made to fit into all the holes at the same time. Unless this is done some of the sleepers are liable to be narrow in the gauge, the result being that the flanges of the wheels either shear the fastenings or else burst the sleeper. In this respect manufacturers on the Continent are subject to strict inspection, a standard gauge being made for everything with little allowance. Even the piles from which the sleepers are rolled are specified. Fig. 29 shows a pile for rolling two lengths of Hilf's sleeper in one

FIG. 29.



bar; these are made most successfully in a three-high mill or in a reversing mill. The tops and bottoms of the pile are of best-best

Digitized by Google

iron, whilst the middle is made of selected puddle bars. In Belgium the soft iron rolls out easily; but, just as in Belgian girders, the iron will stand 20 to 21 tons strain in the line of the grain, but only one-third of this when tested crossways. There cannot be a doubt but that a homogeneous quality of steel for this purpose would be a great improvement.

It is essential that the rails of an iron permanent way be well fished. In Germany this is attracting much attention. The fish-joints are usually of great strength and length; they are made with angles, and are even extended down considerably below the rails, whilst there is plenty of clearance for screwing up as they become worn. These fish-plates are often used with six bolts, and their strength is equal to 80 per cent. of the strength of the rails. This attention in the fishing has also been applied to railways where wooden sleepers are used. Where the old weak fish-plates were employed the rails cut into the timber far more at the joints than elsewhere, and required constant lifting and packing at the joints. Strong fishing is equally important upon one system as upon the other.

Upon wrought-iron sleepers good fishing of the rails is the more necessary on account of that metal not being able to stand a succession of blows, and therefore the more this can be avoided the longer the sleeper will last. The general adoption of steel rails in place of iron in this respect must greatly conduce to their durability. Iron rails are constantly wearing into holes, and this, from the concussion of the wheels passing over, would act injuriously upon the iron sleeper.

It has been the practice, particularly where the longitudinal systems are in use, to recommend lighter rails than were adopted for wooden sleepers, and therefore crediting the iron way with the difference in the cost. This, however, is a fallacy, and it is now generally acknowledged that the same weight of rail should be employed in both cases. Thus, suppose any road with wooden sleepers had a traffic requiring an 80-lb. rail per yard, the same strength should be employed upon an iron permanent way under the same circumstances.

It is difficult to furnish data which would be a guide as to the cost of the various systems on the Continent. The Author, after careful examination, has come to the conclusion that prices would only be misleading. Year by year prices have much altered, whilst the weights of the different systems have constantly been increasing.

Mr. Grüttefien has kindly given the Author the cost per ton of

Digitized by Google

iron permanent ways upon the following railways:—East Markische, Westphalia, Saarbruck, Hanover, Frankfort, Main Hessen, and Nassau: the average price of which was, in 1878, £8; in 1879, £7 10*s.*; and in 1880, £7 per ton; whilst the average cost of timber sleepers upon the same railways during the same periods was 5*s.* each.

Creosoted sleepers with spikes, delivered 2,000 miles from England, cost more than iron sleepers; and timber sleepers in hot countries last from ten to twelve years, whilst large quantities are destroyed before they are put in the ballast from exposure to the weather; iron sleepers in this period of time would not be deteriorated. If therefore the cost of renewal every ten years be taken into account, the saving by the employment of iron sleepers will amount in a few years to about 2 per cent. per annum on the total cost of the railway. In hot damp climates it will amount to even more than this, besides the saving in labour, in maintenance, and in the better state of the roads generally. The Author feels sure that the experience gained, and the confidence which may now be put in wrought-iron or steel permanent ways, will lead to their general adoption. Even supposing timber can be had upon the spot at a little less cost, it would be better for the reputation of the engineer to put in iron, knowing that timber sleepers are often rotten before the contractor gives up the line, and that at any rate even creosoted sleepers will have to be renewed in from eight to ten years, whilst uncreosoted sleepers are often unfit to travel over after four or five years' use. Contractors also should in such climates be thankful when iron sleepers are specified, as the road can go out in such a condition that it can be transported and laid by unskilled labour.

A large amount of information connected with the German States railways, has been kindly supplied to the Author by Mr. E. Grüttefien of the Ministry of Public Works, Berlin. The Author is also indebted to Mr. R. Wright, the Resident Engineer of the Dutch Rhenish Railway at Utrecht, for information of a similar character.

The Paper is illustrated by one Plate (Plate 1) and twenty-nine woodcuts.

Digitized by Google

Discussion.

Mr. R. RAWLINSON, C.B., asked if Dr. Siemens could say anything as to the probability of the introduction of steel and the abolition of iron sleepers. Iron had apparently been used in almost all the cases referred to in the Paper, but he had no doubt that Dr. Siemens, who knew so much, particularly of modern improvements, would say that iron would soon be a past manufacture. Mr. Rawlinson.

Dr. SIEMENS said he was hardly bold enough to make such an assertion; at the same time he believed that steel was on the whole preferable for the new application. While continental nations had been giving great attention to the introduction of metal permanent way, England had remained perhaps too partial to timber as the material to be employed. It was true that English engineers would now have the advantage of the experience already gained, and when turning their minds to the subject they would soon perceive not only the advantage of the metal system, but the most practical mode of carrying it into effect. Iron should be strong enough for the purpose, because each portion of an iron cross sleeper was apparently not strained beyond its capability of resistance; still he apprehended that homogeneity was of great importance, because where the fastening held, the metal was strained to a very considerable extent—an extent which could hardly be determined *à priori*, and in all such cases steel yielded before it fractured under compressive strains. Then again, he believed that the introduction of steel sleepers would be of great advantage to the manufacturer, even though he should not realise large profits from the actual operation. It was well known that in Germany, where iron and steel sleepers had been largely introduced, the manufacturer was glad to supply them at a comparatively low cost, because he could go on with the manufacture without waiting for specifications. It was always the same thing, and whenever he had no other work on hand he could turn to rolling sleepers; moreover, although a good metal should be employed, it was not necessary to use entire ingots, but considering the short length of a sleeper, odds and ends of the material could be utilised to a considerable extent. Therefore he had no doubt that, for the two reasons he had mentioned, the comparatively low price at which sleepers could be supplied, and their great permanency when once laid down, iron or rather steel permanent way would soon be very largely, if not universally, introduced into this country. Dr. Siemens.

Digitized by Google

Mr. d'Avigdor. Mr. E. H. D'AVIGDOR ventured to make one observation bearing upon the question of Belgian girders—a subject of which he knew something, because he had made those girders himself. He took the liberty of challenging the statement in the Paper that in any girders made of Belgian iron the breaking strain transversely was only one-third of the breaking strain longitudinally. Some exhaustive experiments had recently been made in London by eminent persons on various Belgian girders, and such a result as had been mentioned in the Paper had never been even approached. The longitudinal breaking strain, as the Author had remarked, varied from 20 to 22 tons, but the transverse breaking point had never been anything like so low as one-third, or even as one-half, and only in one case was it two-thirds.

Mr. Cowper. Mr. E. A. COWPER wished to direct the attention of the members particularly to the fact that English engineers were so far behind their neighbours in the use of steel sleepers. The advantage of good steel rails and sleepers was now pretty well acknowledged. As the Author had stated, about 200,000 tons of iron and steel sleepers were at work in Germany, and some of them had been laid twenty years, others twelve and fifteen years; so that the experience that had been gained in that country was very great. The Author had pointed out the defects in certain constructions. It would be seen that on the Continent many experiments had been tried with different forms of construction, some of which certainly did not commend themselves to general acceptance. Experiments had been tried in different directions; if any form failed, another was tried; and after gradually simplifying the arrangement, a section had been attained which appeared to be generally approved. He referred to the sleepers on the Bergisch-Märkisch Railway, of which a great quantity had been made. He had thought that after the excellent Paper and discussion at the Düsseldorf meeting of the Iron and Steel Institute, last year,[1] the attention of English engineers would have been given to the subject more closely than it had been. He had on several occasions expressed his opinion that in a few years the public would be travelling over steel sleepers. He hoped the shareholders and the directors would take the subject into consideration as well as the engineers. Mr. Webb's sleeper, with riveted jaws, had been laid for some months on the London and North

[1] *Vide* "On the results obtained with various systems of iron permanent way in Prussia," by E. Grüttefien. The Journal of the Iron and Steel Institute, 1880, p. 488.

Digitized by Google

Western line, and he hoped that other lines would follow suit. He thought that the sleepers should be made of steel, not of iron, steel being more tough and springy, as well as much stronger, and they could be made much lighter. The end should be turned down, so as to give resistance to motion, and this could be done easily and cheaply. At the German Steel Works, last year, he saw sleepers rolled for the Bergisch-Märkisch Railway, in lengths of 60 or 70 feet. As the metal emerged from the rolls, lengths were sawn off, which were carried forward, the holes punched, the ends slit and turned down, and the sleepers set to a slight curve, to give the inclination to the rails. The whole punching and bending was done for about 1½*d*. He agreed with Dr. Siemens that many odd scraps might be used up for the jaws and the chairs with a view to economy. He had long considered the use of steel for sleepers. Large sums of money now spent for wooden sleepers might be saved, and a double demand for steel would be made upon the steel works, the sleepers weighing quite as much as the rails. It was true that sleepers would last a long time when once made; but then all the lines would have to be supplied with them from the first, because the wood would be gradually displaced. Looking at the fact that 200,000 tons of iron sleepers had been laid in Germany, and were working for the most part successfully and economically, he thought English engineers would be very much to blame if they did not benefit themselves and the public by the use of steel sleepers within a very few years. Mr. Cowper.

Mr. James Livesey said that the subject was becoming of great importance, and the experience of those who had been for many years engaged in connection with it might be of some value to the Institution. Twenty years ago his attention had been directed to the subject of iron permanent way; and, before recommending any particular class of iron permanent way, he resolved to make some exhaustive experiments on the North London Railway, with a view of testing the various ideas he had upon the subject. At that time he entertained the opinion that an elastic permanent way would be a great improvement, and he resolved to test, not only the question of elasticity, but other questions in relation to iron permanent way. Having obtained permission to make his experiments, he had a large quantity of sleepers cast, and his first experiment was with a cast-iron bowl sleeper of an oval form. The rail was fastened to the sleeper by means of an iron key, the rail being bedded on the body of the sleeper, iron to iron. He then put down a length of road with wooden blocks interposed between the rail and sleeper; then a length with pieces of india- Mr. Livesey.

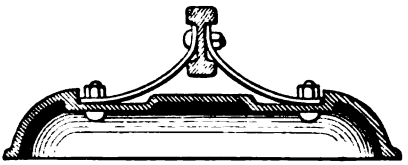
Digitized by Google

Mr. Livesey. rubber ¼ inch thick interposed between two blocks of wood; then he had india-rubber placed between the timber about ½ inch thick (Fig. 30); and beyond that he had a length put in with rails

Fig. 30.

secured on steel springs (Fig. 31). He had watched the experiment with great interest for a long time, and it was difficult to discover which road gave the best results. The first road seemed to stand the best; but it was for a long time difficult to discover very much difference. After some months, however, when bad weather came on, it was found that the sleepers that had any degree of elasticity

Fig. 31.

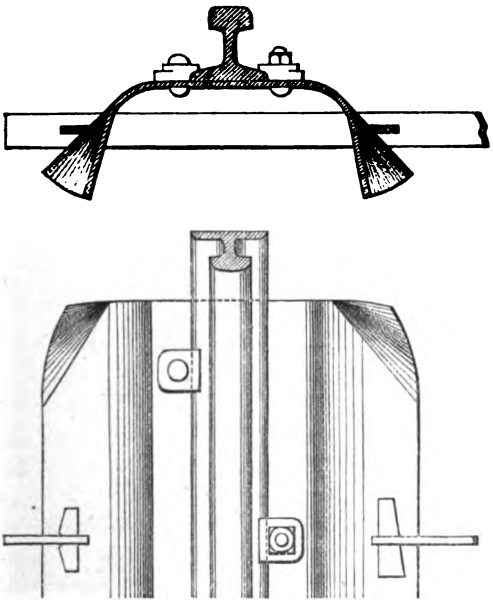


gave a great deal of trouble—even those with the small piece of india-rubber. The little motion that the sleepers had rendered frequent repairs necessary. The road on steel springs seemed to promise well at first; but when wet weather came the sleepers were so lively in the ground, and the repairs so great, that this part of the road had to be taken up. The result of his experiments was that he abandoned altogether the idea of adopting an elastic sleeper or putting in an elastic medium, except, perhaps, a wooden block between the rail and the sleeper. These sleepers stood the heavy traffic of the main line of the North London Railway, giving no indication of weakness in any other point. The system had been examined by many engineers, and the result was that upwards of 200,000 tons of similar sleepers had been laid in various parts of the world, giving, he believed, great satisfaction, and their use was being largely extended. Soon after making the experiments he wished to try the result of a wrought-iron sleeper, and obtained permission to make experiments on the Great Eastern Railway. The Author had stated that from 1855 to 1878 no wrought-iron permanent way had been tried in the country.

Digitized by Google

During that period, however, Mr. Livesey had been making many experiments with wrought-iron sleepers, especially on the Great Eastern Railway. The sleeper was a simple plate, bent in the form of a saddle, and strengthened by a tie-bar passing through (Fig. 32). It made an exceedingly easy road to travel over; and he found that ¼-inch plate was sufficient to stand all the main line traffic of the Great Eastern Railway. Some interest was taken in that form of sleeper by engineers; and about 16,000 tons had been Mr. Livesey.

FIG. 32.

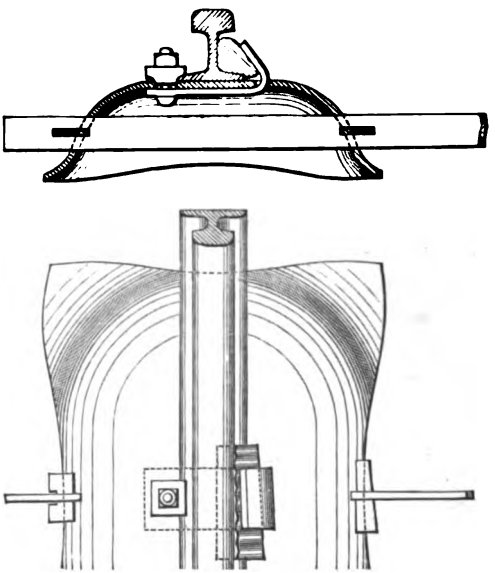


made during the last ten years. He believed the only point of trouble with them was that the hook-bolt on the inside clip of the rail had not a sufficient bearing surface; but the outside clips, which were riveted down, had given no trouble. He had been anxious to obtain, if possible, a stronger form of sleeper, because, if anything, that form of sleeper was a little too elastic. For some time he tried to get the manufacturers to make a bowl form of sleeper out of a rectangular plate (Fig. 33). Being so made it would be exceedingly strong. There was no waste in its manufacture, and the flat corners of the sleeper gave more bearing surface, besides having the advantage of the greatest depth of ballast being on those corners, and the sleeper was thereby anchored

Digitized by Google

Mr. Livesey. down in the ballast. A great many sleepers of that pattern had been made, and were now laid on many railways in various parts of the kingdom. The illustration by the Author (Fig. 27) simply showed a jaw riveted to the sleeper, and a corrugated iron key; but one objection to that arrangement was that the gauge could not be adjusted. In the bowl form of sleeper which he had just described the gauge could be adjusted by the back-stop, the bolt-hole in which was placed eccentrically, so that by turning it in one direction the gauge was made a little wider, or in the other

FIG. 33.



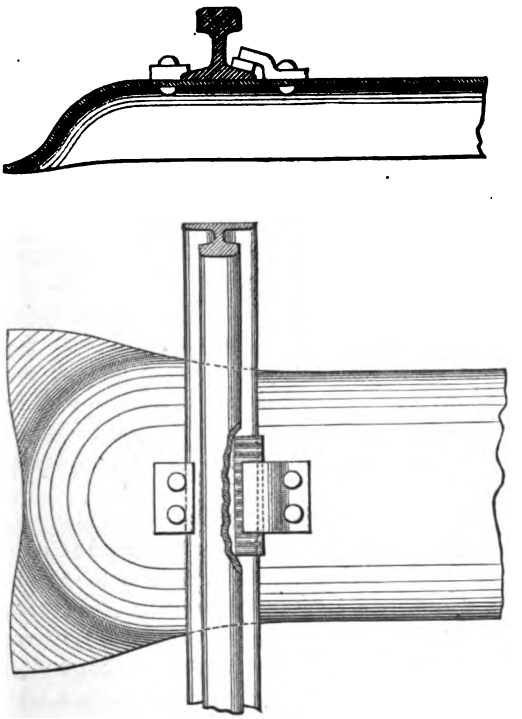
direction a little narrower. That arrangement of sleeper also was giving great satisfaction. The Author had stated that there was no necessity for turning down the ends of the sleeper. Mr. Livesey had recently been in Belgium and Germany, where he had seen thousands of sleepers on various lines, and in every instance the ends had been turned down, showing that experience abroad at any rate was in favour of that method being adopted. He had seen a long time ago that this was a necessity. When Mr. Barningham and he were making experiments on the Great Eastern Railway, the platelayers used to say that the great trouble with the open-ended transverse sleeper was that the road got so much out of form that it was a "floating" line. He then saw

Digitized by Google

the necessity of turning down the ends of the sleepers, and adopted that method. On the South-Western Railway open-ended sleepers were tried, and they were found not to give satisfaction. They moved sideways. Mr. Livesey.

Considering the different kinds of ballast on various lines and under so many varying conditions, it required only a little discernment to see that a sleeper with closed ends became almost a

FIG. 34.



necessity. With wet, sloppy ballast and on curves an open-ended sleeper opposed little lateral resistance, and was what platelayers so aptly called a "sliding or floating" permanent way. The few experimental lengths of road tried in this country, and under favourable conditions of ballast, curves, &c., afforded very little guidance. Experience became valuable after many years of trial in different countries under varying conditions.

The Author of the Paper had indicated the best kind of ballast to be employed. It was certainly more easy to say what was the

Digitized by Google

Mr. Livesey. best ballast than to procure it. In the neighbourhood of Middlesbrough, where the Author had conducted his experiments excellent ballast could be procured without difficulty; but since an engineer had to deal with various physical conditions in all parts of the world, he must be prepared to adapt his designs thereto. In the Argentine provinces there were hundreds of miles of railway where neither broken slag, broken stones, nor gravel of any description could be had, but ballast consisting of black soil only. At certain seasons of the year, the rainfall was very heavy, and at others there was a continuance of dry, hot weather for months. It had been found that the cast-iron bowl sleeper answered admirably, and met the peculiar conditions in a singular manner. The bowl of the sleeper held a good body of soil ballast, which became hardened and was not easily washed away. Gradually the soil under the sleeper was consolidated, until a kind of pyramid was formed under each sleeper. When the heavy rains set in, the ballast in the centre of the road and around the sleepers was often washed away, but the earth was so indurated under the sleepers that very little disturbance followed. A timber-sleepered line had been impassable, when the iron sleepers stood firmly on their pyramidal beds, though the earth around had been washed away; thus showing that the form of sleeper played an important function. A flat sleeper, for instance, might do well in favourable ballast; but his experience was, that a sleeper holding a good body of ballast met such varying conditions, as had been alluded to, better than any other.

Speaking from experience extending over many years and on railways with which he had long been connected as engineer, he found that the girder-class of road was far too rigid and severe, and if with a sufficient amount of bearing area (other conditions being equal) it was more expensive than the transverse or bowl system, both of which, if properly constructed, had given excellent results. The determination as to whether a transverse or a bowl system should be adopted, depended in a great measure on the gauge of the line. For equal effective bearing areas, the cost of the two systems was about the same, with the 3-feet or metre gauge; but for a wider gauge, the transverse system was more costly. For a gauge of 5 feet 6 inches, the difference was considerable. With a bowl sleeper the extra cost was simply the additional length of tie-bar, which amounted to a mere trifle; but with the transverse sleeper, it came to the cost of so much of the entire sleeper.

Next to the form, and equal in importance, was the rail-fastening.

Digitized by Google

Since iron sleepers were intended generally for countries where there was little skilled labour, it was important to have as few loose pieces as possible, and those of a simple kind. The bulk of the cast-iron sleepers he had so largely adopted and introduced, were of deep bowl form, and oval, so as to obtain a long bearing for the rail. The key was of cast iron and was corrugated or serrated on one of its faces, fitting into corresponding corrugations in the jaw of the sleeper, which was made of steel, cast firmly into the body of the sleeper, and was elastic enough to allow the corrugations to pass each other. The key was driven in and out in the usual manner by a platelayer's hammer, and when driven, no vibration of the road could shake it out. The road was held to gauge by a tie-bar with a single cotter to each sleeper, which could not be wrongly placed. Mr. Livesey.

It had been found that large surfaces were necessary for the outside edges of the flat-bottomed rail to bear against. The comparatively sharp edge of a Vignoles rail made, in four or six years, a perceptible indent in the outside jaws against which the rail abutted. This action went on increasing, and the result was that keys became loose and the gauge of the line deranged. It was, therefore, important to have all bearing and wearing surfaces as large as possible. He had also discovered that, on wrought-iron sleepers, it was especially important to have the parts forming the rail fastenings rigidly and immovably secured to the sleeper. If any part had the least chance of motion or vibration, however slight, destructive wear set in. A well-riveted abutment, or back-stop, on the outside edge of the rail, offering considerable wearing surfaces, and a riveted elastic key-jaw on the inside would last as long as the sleeper itself. This arrangement of rail-fastening was shown by the Author of the Paper at Fig. 27. The only loose part was a corrugated iron key, which, when driven, could not shake loose.

It was a great advantage not to have any loose parts to fit into the sleeper on the ground. All parts should be rigidly and permanently secured at the works, and form an integral part of the sleeper. The sleepers could then at once be placed in position on the ground, the rail inserted, and by simply driving in an iron key, the road would be permanently laid. Such a road could be laid by unskilled labourers.

The strong form of the transverse sleeper with bowl-formed ends, and the bowl-sleeper itself, allowed a very light plate to be used, either of iron or steel, which effected a very considerable saving in weight. For securing the rail-fastenings to wrought-

Digitized by Google

Mr. Livesey. iron sleepers, it was important to have strong washer-plates under the head of either rivets or bolts. He found, where fastenings had been employed that could vibrate in the least degree, that in the course of years the plate was gradually worn through; and often these points of weakness did not develop to any serious degree for a number of years. He had seen examples that had been in the ground eleven years, and found the sleeper practically as good as new, with the exception of one or two weak points, which had the effect of rendering the sleeper prematurely useless.

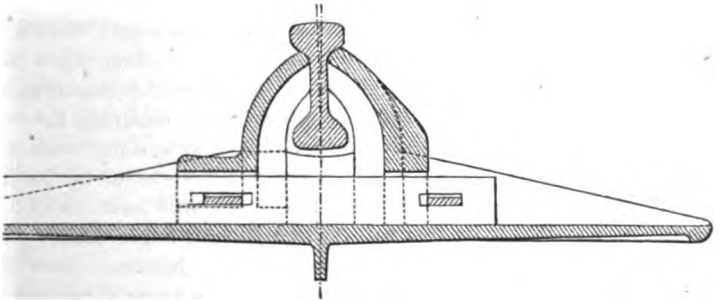
He could not agree with the Author of the Paper, either as to the form of sleeper which he recommends, or as to the mode of securing the rail. The grounds of objection to the open-ended sleeper had already been given, but the effect of bending the sleeper so as to dip towards the centre of the road was, in his opinion, to lead the water in that direction instead of towards the outside of the road. For climates where long-continued and scorching heat was followed by extreme moisture, a wooden key for securing the rail was objectionable; for not only did it shrink, but wear was constantly going on. Even in the damp climate of England, it was well known what trouble the wooden keys gave on railways. With the ordinary cast-iron chair, the keys working loose and dropping out here and there was not of vital importance; but when the permanent security of the chair itself depended upon a wooden key, which had to answer the double purpose of securing the rail to the chair, and the chair to the sleeper, the arrangement did not seem to offer that reliable security which ought to be looked for in a sleeper, which the Author of the Paper said ought to last thirty years. He had pointed out the destructive effects produced by motion of the parts on wrought-iron sleepers. Now the Author admitted that a few of the keys on his experimental length had come loose. If this was so with an experience of only three years, during three wet winters and three remarkably wet summers, what would be the result of an exposure of many months under a tropical sun? The elasticity of the jaw was an advantage to a certain extent, but, in his opinion, the range of elasticity was not sufficient to meet the shrinking and wear of a wooden key. For many years he had employed the elasticity of a steel key-jaw and other elastic arrangements in connection with a corrugated or serrated iron key; but even with this, consequent on the wear that took place, the keys occasionally required to be tightened up. The Author had been at great pains to collect information from foreign engineers, which together with the opinions expressed by English engineers would be found of some value, as it would

Digitized by Google

enable engineers to avoid errors and weak points that could only be discovered after long experience. Mr. Livesey.

Mr. Bradford Leslie remarked that in India the high cost and rapid decay of timber had long ago compelled engineers to have recourse to iron for sleepers. The renewals of timber were not less than 10 per cent. per annum, while the renewals of iron did not exceed 1 per cent. His experience was chiefly with cast iron, but as it had been said that within twelve months wrought iron would be a thing of the past, he feared cast iron would be considered as already quite out of date. Yet there was something to be said in favour of cast iron: in the first place, it was cheap; and in countries like England and her dependencies, where the double-headed rail requiring lateral support was in use, the vertical jaw for this purpose was more easily provided in a casting than in any description of wrought-iron or steel sleeper. Another advantage of cast-iron sleepers in India, where there were no rolling mills, was that cast scrap was more valuable than steel or iron scrap. Scrap-sleepers were recast on the spot, but wrought- Mr. Leslie.

Fig. 35.



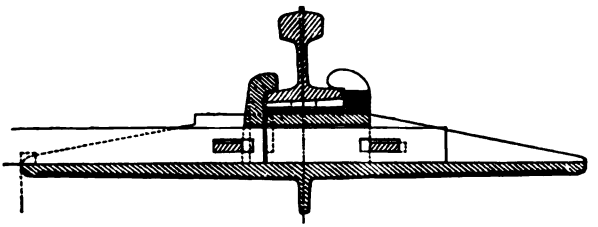
iron or steel scrap had to be sent across the sea to be worked up again. He had further to observe that, in adopting any form of channel bar as a transverse sleeper, there must necessarily be a great waste of material in the centre, even with the 4 feet 8½ inches gauge, and where, as in India, the standard gauge was 5 feet 6 inches, such a section would be inapplicable. He had found that where sand or loam was available for ballast, Greaves's old-fashioned surface-packed pot-sleeper made an excellent road. With a hollow bearing, however, of any description, it was more difficult to get a good "top" on the road and to keep it, than with a flat bearing; and for use on broken stone ballast for renewals promiscuously with timber sleepers, a cast-iron sleeper, called the Denham-Olpherts sleeper (Fig. 35), was used, consisting of a pair of

Digitized by Google

Mr. Leslie. flat plates, with stiffening ribs on the upper sides and external fixed jaws. A wrought-iron tie-bar passed through the fixed jaws, and by means of cotters at the back of the jaws connected the plates together and regulated the gauge. An internal loose jaw slid between the stiffening ribs of each plate, and was pressed firmly against the rail by a taper key passing through a hole in the loose jaw, and a corresponding hole in the tie-bar. By this arrangement the rail was suspended and firmly gripped between the jaws.

The East Indian Railway was originally laid with transverse timber sleepers, and these cast-iron plates (Fig. 36) had been used

Fig. 36.



instead of timber for ordinary renewals, so that there were commonly three or four timber sleepers and as many cast-iron sleepers in the same length of rail. Whether used in this way or continuously, they made an excellent road for heavy and high-speed traffic; and excepting in the case of a few defective castings there were no breakages. The weight of the plates was 100 lbs. each. The cost of the complete sleeper with all fastenings, including the chair for support of the double-headed rail (which the Author's sleeper did not provide), delivered at the East India Railway, was 9*s.* 10*d.*

Mr. Blair. Mr. James M. Blair presumed the numerous types of longitudinal sleeper described in the Paper as having been tried in this country, had been mentioned as a matter of interest to engineers, but not as examples to be copied. The transverse sleeper, undoubtedly, had a great deal of merit, and he thought that the Author's system was about the best of any. It was a singular circumstance that the first longitudinal sleeper, Mr. Barlow's, was one of the best, and the same remark he thought applied to the transverse sleepers. The first of them, Mr. Le Crenier's, in 1860, the only one not illustrated, was very much of the same model as the Author's, which, however, had certain improvements. Mr. Blair made the sleepers that were laid on Mr. Le Crenier's system in Portugal. There was a wrought-iron plate following the rim or section of a transverse timber sleeper, somewhat as

Digitized by Google

shown in Fig. 28, but the tilt of the rail was impressed into the sleeper in the same operation as bending the plate. The Author's system had an improved fastening for the rail, and an improved section for the transverse sleeper, but the plan of following the section of the wooden system seemed to be almost the same. He thought the Author had carried them far enough in the direction in which he had gone. In some instances the transverse sleeper was impracticable on account of extra cost of transport or manufacture, especially in the case of broad-gauge railways. It might be suitable for the ordinary gauge, but for broad-gauge lines there was an extra element of expense. Many other systems had been adopted. There was the cast-iron pot sleeper with a tie-bar, which had served its purpose very well. With regard to the question of steel or iron, he was glad to notice in the Paper some remarks as to the liability to corrosion. That was one point which for a long time had prevented engineers from adopting wrought-iron or steel sleepers. It had been proved that there was very little liability to corrosion in an iron permanent way where there was an existing traffic; but where the line was at rest corrosion would soon take place. Where traffic existed, the corrosion was almost nil. That was a point in favour of thin plates of iron or steel for permanent way. It was a good many years since wrought-iron plates $\frac{1}{4}$-inch thick had been used. They had been thoroughly tested, and did not fail on account of corrosion. Many other plans had been tried, and he thought that Mr. Livesey's was about as good as any brought before the meeting. Steel, however, was no doubt an advance. He considered that $\frac{1}{4}$-inch plate of iron was ample. Many hundreds of miles had been made of $\frac{3}{16}$-inch plates, and he had made steel plates less than $\frac{1}{8}$ inch thick. They had been tested with heavy engines, and had been found quite fit to stand the heaviest traffic. Steel plates $\frac{1}{16}$ inch would be ample, if they were not liable to corrosion. With regard to some transverse sleepers, such as shown by Mr. Livesey, there was an objection to them on account of their getting rigid in the centre, so that when the pressure came on the rails the ballast was depressed under them, and the transverse sleeper rode on a ridge in the centre. With the ordinary pot sleeper, either wrought iron or cast iron, there was not so much liability to this occurring, he thought, as in the case of the transverse sleeper.

Mr. Blair.

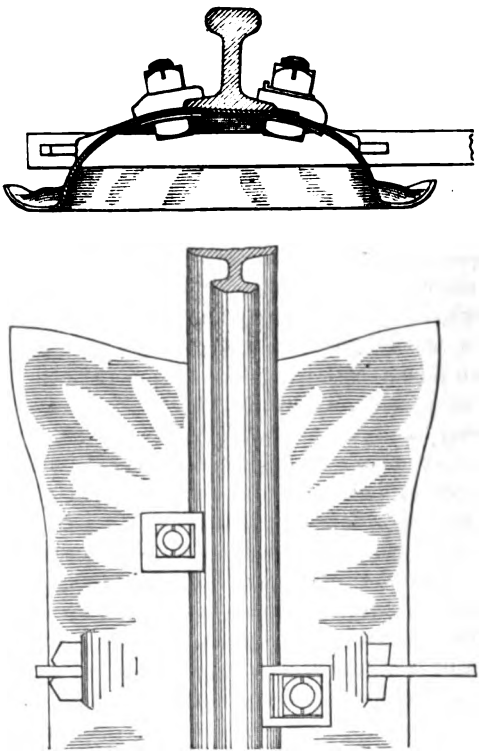
It might be assumed that engineers of the present day generally felt assured that steel was the metal of the future, and was destined largely to replace cast and wrought iron in structures where strength and lightness were essential. He believed it was

Digitized by Google

Mr. Blair. a metal peculiarly adapted for the permanent way sleeper-chairs of railways. On this account he submitted some forms of embossed steel sleepers. It had been found that the corrugated form imparted considerable extra strength, and in point of manufacture afforded a ready way to dispose of the metal, and thus avoid the severe strain to which the plate was subjected in making the plain form of bowl sleeper.

The sleepers (Fig. 37) of $\frac{3}{16}$-inch steel plate, were the form adopted by the Oude and Rohilkund Railway Company, a railway

FIG. 37.



which had shown the lowest cost for maintenance of any in India. These sleepers had been tested by pressure to 25 tons without retaining any permanent set. Some hundreds of miles had now been laid, many of which had been down for six or seven years, and had continued to give the most satisfactory results.

The rail clips were fastened by a bolt and nut. This, he con-

Digitized by Google

sidered, was better than a plain rivet, insomuch as the point of the bolt was intended to be riveted over the nut, thus effectually preventing the nut from coming off; but, in case of slacking, it could be more easily tightened than a simple rivet. For the sleepers adopted by the Oude and Rohilkund Railway Company the bolts were of steel, with steel lock-nuts, and having one of Sterne's locking-washers under the nut. There was also a 3-inch square washer between the head of the bolt and the under side of the sleeper. This rail-fastening had answered well, and gave no trouble. Mr. Blair.

He thought that what was sometimes described as the chattering of the fastenings in new sleeper-chairs, could be obviated at little cost by introducing a thin layer of felt, or other fibrous material, or even sheet lead, between the rail and the sleeper. Wood cushions had been used for this purpose, but he did not know if what he now suggested had been tried.

The embossed steel sleepers, made of plates $\frac{3}{32}$-inch thick, were not thought strong enough to carry the tie-bar through the sleepers; an independent tie-bar had therefore been adopted, of angle or other suitable section, with proper fastenings to the rail, and so formed as effectively to hold them, both as to tilt and gauge, the sleeper chairs serving only to support the railway on the ballast (Fig. 38). By this arrangement a better tie was obtained, bearing directly on the rails, which were thus more easily held rigidly in position.

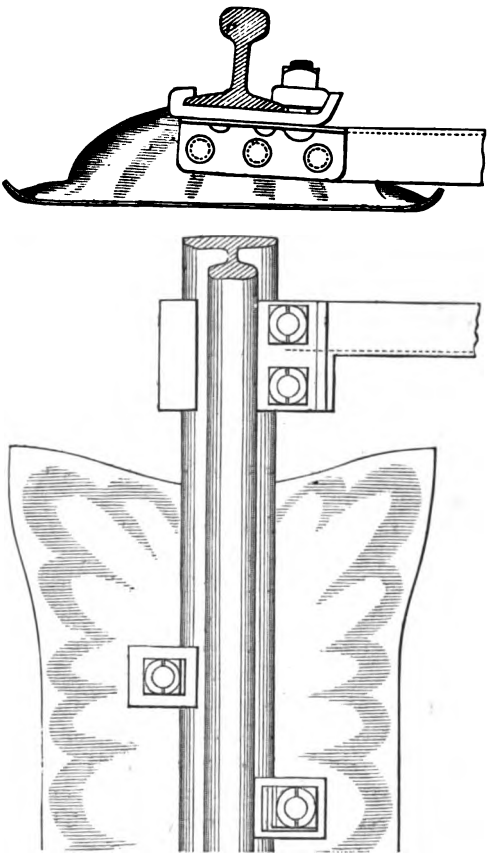
A short piece of railway of this description, with sleepers $\frac{3}{32}$-inch thick, had been laid some time ago in Clutha Iron Works. The sleepers were laid on iron plates, so that their action could be well observed. A powerful locomotive engine, weighing 45 to 50 tons, was passed over them several times slowly; it was also made to rest with the driving-wheels directly over the sleeper chairs; and was run across them at such speed as could be attained in about 100 yards, without visibly affecting them in any way. In addition to this, a $\frac{1}{2}$-inch plate was placed under one of the sleepers, thereby partially suspending those on each side and bringing greater stress on the elevated one. The engine passed over this without any visible effect. Subsequently another plate was added, thereby raising the sleeper about an inch, but with the same result, as even under these circumstances it withstood without change the extra strains brought on it.

The sleeper chairs of $\frac{3}{16}$-inch plate iron had hitherto been pressed hot, and were completely finished at one operation. Mr. W. F. Batho, M. Inst. C.E., the engineer of the Oude and Rohilkund Railway Company, had for some time urged their being

Digitized by Google

Mr. Blair. cold-pressed. With the aid of improved and more powerful machinery this was now being done. The saving of cost of heating, and waste from scale formed in the furnace, was an important factor; but by this mode of manufacture the scale, or black oxide, formed in rolling the plate was entirely removed, and the sleeper

FIG. 38.



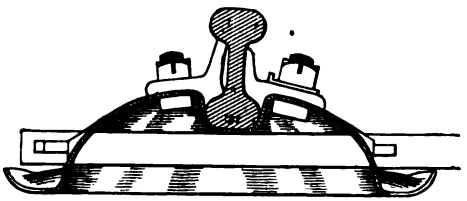
was thus left in a better condition to resist the action of corrosion, or to receive any coating that might be applied.

With regard to coating, in his opinion nothing better had yet been found than Dr. Angus Smith's composition. This effectually preserved them until they were laid on the railway, and had traffic passing over them, after which the corrosion became inappreciable. He had had some coated by the Barff process, as a

Digitized by Google

trial, but found that very little straining in a hydraulic press made the magnetic oxide come off in scales, so that this system was not applicable for coating metals subjected to straining. He was not aware if galvanising had been tried; but he thought Mr. Blair.

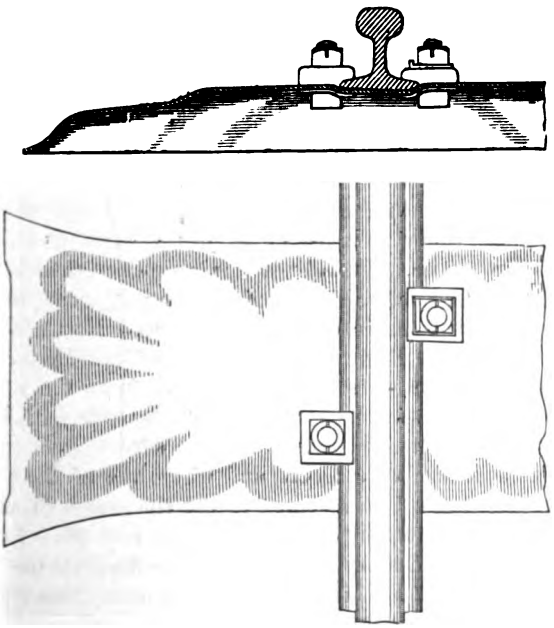
FIG. 39.



that in many circumstances this coating might be adopted at little cost, especially in connection with very thin plates.

He thought the cost of steel sleeper chairs, such as those he had described, would bear very favourable comparison with either cast-iron or timber sleepers. Steel sleeper-chairs were not one-

FIG. 40.



third of the weight of cast-iron chairs, and thus a great saving was effected in freight and carriage. In addition to this, there

Digitized by Google

Mr. Blair. was the loss from breakage in cast-iron sleepers, which was entirely avoided in steel. He therefore considered the time not far distant when they would, to a large extent, supersede both cast-iron and timber sleepers.

This sleeper was especially adapted for the flat-bottomed section of rail, but Fig. 39 showed the form suited for a double-headed rail.

An embossed steel transverse sleeper, adapted for metre or other narrow-gauge railways, was shown in Fig. 40. The rail fastenings were similar to those already described. These sleepers could be delivered in India at about the same cost as creosoted timber sleepers.

Mr. Bruce. Mr. G. B. BRUCE said that Mr. Cowper had drawn attention to the large use which had been made of malleable iron sleepers on the Continent, and the very slight use made of them by English engineers, which he regarded rather as a reflection upon the latter for not being sufficiently progressive, and as a commendation to the former for their spirit in having done so much in that direction. It appeared to him that English engineers had been wise in their generation, that their caution and slowness had been wisely manifested, that they had shown their judgment as engineers and their care for the shareholders whose interests they represented, because he ventured to think that from the beginning to the end the Paper was more or less a record of failures. There was scarcely any, if any, system of permanent way laid with malleable iron sleepers, transverse or longitudinal, of which it was not stated that in some direction or other it had failed. In many cases it appeared that the system was no longer adopted on the main line, but only in sidings; in other cases the fastenings rattled and got loose. He did not think anything had been stated which would lead an engineer of sound judgment to trust to such a system the traffic of the London and North Western or the Great Northern Railways. The great difficulty on the Continent no doubt arose to a large extent from the use of the Vignoles rail, which appeared to him incompatible with the use of malleable iron or steel sleepers. It was a very good rail where laid upon cross timber sleepers, and where the traffic of the road was such that it could be fastened to the sleepers by the ordinary dog spikes, or at most by a fang bolt here and there; but when the rail was fastened to an iron sleeper with all the contrivances of bolts, screws, clips, and the like, and in some cases gibs and cotters, there must necessarily be a good deal of shaking, and it was very difficult to fasten the Vignoles rail to an iron sleeper in any other way. The only iron cross-sleeper permanent road that

Digitized by Google

commended itself to his judgment was that used by Mr. Webb on the London and North Western Railway; it appeared to him to be the nearest, if not the only, approach to anything like a perfect permanent way. He believed that there was something in it foreshadowing the sleeper of the future. Mr. Webb had a good strong heavy steel or malleable iron sleeper on which he had riveted steel chairs, well made, and the whole formed a heavy and stable permanent way. The Author's method was an ingenious mode of fastening the rail; he had adopted, like Mr. Webb, the ordinary old-fashioned wooden key, which was by far the best. He had made some inquiries with regard to the Author's permanent way, and had found that although it had many good qualities, several of the sleepers had split underneath the rail. With regard to the horse-shoe clip mentioned in the Paper, the shoulders, where they bore upon the underside of the sleeper, were wearing very rapidly. That probably was the fault of the construction in the first instance; had they been larger they might perhaps not have worn in that way. He thought that Mr. Webb's permanent chair riveted on to the sleeper was much better than any loose method like the Author's, however ingenious. There was one difficulty in connection with all hollow malleable iron sleepers—the difficulty of packing them. They were not nearly so easily packed as wooden sleepers. The gravel underneath got hard and compact, and when the platelayers lifted the road they had to break up the ground before the road could be properly packed. That was a disadvantage, and added materially to the cost of the road. He thought it probable that the sleeper of the future might be a soft steel one, with a steel chair riveted to it; but he was strongly of opinion that none of the contrivances of bolts, gibs and cotters would ever answer. With regard to cast-iron sleepers, he could confirm what Mr. Leslie had stated, that a large number of those in India stood admirably. He had laid many miles in India of Greaves's pot sleeper with a depression in the centre, and the rail resting on wooden cushions on each side. The breakage was practically nil, and for a road of moderate speed and weights, he did not think any better system could be adopted. It was a very different matter with the great speeds and heavy weights of this country.

Mr. Bruce.

Mr. H. Law desired to direct attention to the statement in the Paper alleging the superior stability of a cross sleeper compared with a longitudinal roadway, which he thought might lead to a false impression, because the measure of the stability of the rail was the area of the surface of the sleeper which bore upon the ballast multiplied into the distance of the centre of pressure from

Mr. Law.

Digitized by Google

Mr. Law. the centre of the line of rails. It would be seen from the diagram (Fig. 28) that unless the cross sleepers were very large or very close the stability of the longitudinal sleeper would be greater than that of the cross sleeper. The points of the cross sleeper were of course more distant; but inasmuch as the centre was so much nearer, it was the centre of pressure which should be considered, and not the extreme point of the sleeper. He wished also to draw attention to the fact that in considering the question of permanent way it was quite as important to look at the wear and tear of the rolling stock as it was to look at the wear and tear of the road. In the Paper, and in the observations which had been made upon it, nothing had been said as to the comparative effects of the various permanent ways upon the rolling stock itself. The experiments upon the North London Railway, where successive short portions of different permanent ways were laid down, might lead to conclusions as to the relative wear and tear of the permanent ways, but not as to the effect upon the rolling stock. The experiments might lead to the belief that an inelastic road was the best so far as the road itself was concerned, but he thought that could hardly be the case when the effect upon the rolling stock was taken into consideration.

Mr. Williams. Mr. R. Price Williams said the remarks made by Mr. Bruce entirely accorded with some of the observations he had intended to make, especially as to the Paper being practically a record of failures. Mr. Webb had furnished him with several details of the cost of his iron and steel sleepers, which fitly supplemented some of Mr. Bruce's remarks. These afforded an answer to the main question in the Paper, namely, as to the relative advantages of iron and steel sleepers, not upon lean traffic lines, such as those to be met with in agricultural districts, but upon severely worked main lines, where sleepers were not destroyed by decay, but had their lives hammered and pounded out of them by heavy and rapid traffic. The Author had given particulars of the average life of oak, and of red and white deal sleepers, showing that they endured longer when preserved, and for much shorter periods when unpreserved; as a matter of fact, however, this was not a question of the average life of sleepers, and it would not do to take into account the element of natural decay when associated with the long life of sleepers on lines of light traffic in this country. On main lines of railway practically no advantage resulted from the life-preserving action of creosote under such circumstances. A life of six years on the main line of the London and North Western was in fact unattainable. He had carefully examined Mr. Webb's iron sleepers, which had been laid for

Digitized by Google

Mr. Williams.

nearly two years, and from his own and Mr. Webb's observations, he found that up to the present time the cost of repairs had been practically nil. The Author of the Paper did not appear to attach much importance to the question of the first cost of the sleepers, because he said the prices varied, but Mr. Price Williams thought that the only requisite for instituting a reliable comparison between the cost of different forms of iron sleepers was the adoption of the same price of materials in each case. From a reference to the tabular statements, which he had prepared from the data furnished by Mr. Webb, it would be seen that an equation had been brought about in the cost of the steel and the wooden sleeper road, a result which he was not quite prepared for at this early period:—

COST OF WOODEN SLEEPER, WITH CHAIRS, KEYS, &c.

	s.	d.
1 wooden sleeper, adzed and bored	3	7
2 B 1 8-inch chairs	2	8
4 galvanised screws	0	7½
4 spikes	0	3½
4 trenails	0	1½
2 pieces of felt	0	2
2 keys	0	3
Total cost per sleeper	7	8

COST OF IRON AND STEEL SLEEPERS, CHAIR BRACKETS, &c.

Weight of Materials.

	Iron Sleepers. Cwt.	qrs.	lbs.	Steel Sleepers. Cwt.	qrs.	lbs.
1 sleeper punched	1	0	26	0	3	16
4 chair brackets	0	0	22½	0	0	22½
2 liner plates	0	0	12¾	0	0	12¾
12 rivets	0	0	5	0	0	5
	1	2	10	1	1	0

Cost of Material—Steel Sleeper.

	s.	d.
Steel sleeper, 1 cwt. 1 qr. at £5 5s.	6	7
2 keys	0	3
	6	10

Cost of Labour on 374 Iron Sleepers.

	£.	s.	d.	
Smiths' work	3	11	8	
Shoring	1	18	4	
Punching and putting together	3	17	11	
Riveting	4	13	6	
Painting	1	11	2	
	15	12	7	
Cost per sleeper— £15 12 7 / 374 =				0 10
Total cost per steel sleeper				7 8

Digitized by Google

Mr. Williams. Having regard to the satisfactory behaviour of these sleepers, and the enormous amount of traffic which had already passed over them on one of the most severely worked portions of the main line of the London and North Western Railway, he was disposed to agree with Mr. Bruce in thinking that something which deserved the name of a permanent sleeper road had at length been discovered.

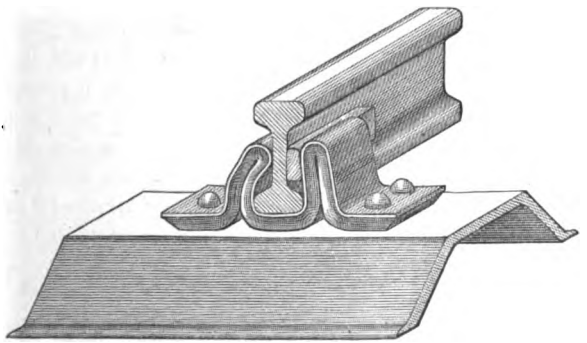
Mr. Rapier. Mr. R. C. RAPIER thought it would be hardly wrong to say that the leading characteristic of permanent way had hitherto been that there was nothing permanent about it. It could scarcely be satisfactory to any engineers, in an essentially iron country, to know that their permanent way required complete renewal every few years. The Author of the Paper had been favoured for the last few years, by the low price of iron, in the endeavour to produce an efficient iron permanent way. He had taken up much the same ground as that occupied ten years ago by Mr. Livesey, who had attained considerable success, but who unfortunately was overtaken by the great rise in the iron markets during the years 1872, 1873, and 1874. At that time the price of iron rose to a point which precluded the use of wrought-iron sleepers. With the present price of iron, sleepers could be made at about the figure given by Mr. Price Williams; but even if there should be a considerable rise in the price, he thought the capital account might fairly be debited with some portion of the cost of the iron permanent way, say not more than the value of the old material; which in the case of iron sleepers he thought might be about half the original cost. So that, favoured by the low price of iron and by the inventions of many ingenious minds, there appeared to be now a prospect of producing a really permanent iron way. Up to the present time, for the traffic on high-speed lines, nothing had been so good as the square 12 inches by 6 inches sleeper held with wooden fastenings; but no one could consider that method as really satisfactory and permanent. With iron sleepers difficulties arose in the fastenings much greater than with wooden sleepers. In the latter the weakness was essentially in the sleepers; in the former the trouble was all in the fastening; the screws would work loose, even if they were riveted over, and the clips of course set up a chatter. There was nothing for it but to rivet one jaw of the chair securely on with two or three rivets to the sleeper. That method of fastening commended itself to his mind, as more satisfactory than any system of bolting or keying. The element of cost was a cardinal one. It might be well worth while in the North Eastern districts

Digitized by Google

to try and develop the use of wrought-iron sleepers; because, if the world were satisfied that iron was the proper thing to make sleepers of, Middlesbrough must flourish, and consequently the North Eastern Railway. It was satisfactory to know that some assistance in the development of the question had been derived from a purse so well able to bear it as that of the North Eastern Railway. He thought it was only fair to advert somewhat more fully than had hitherto been done to what had been accomplished previously by others. He had lately inquired how Mr. Livesey's wrought-iron sleepers had been getting on. Many of them were fastened with rivets, much in the way now proposed by Mr. Webb, one side of the jaw being riveted on with a space left in which to insert an iron key, the other jaw being a fixture. It would never answer to leave the ends of the sleepers open; the road, round curves especially, would travel outwards. He had seen even wooden sleepers, where the platelayers had been obliged to pack up the ends tight and solid, to prevent the road going out bodily on a warm day. The more square the angle at which the end of the iron sleeper was closed the better, so as to get a good end-way hold on the ballast. Mr. Rapier.

Mr. Russell Shaw said that a sleeper resembling that of Mr. Webb was patented in England in 1860, and had been in use in Mr. Shaw.

Fig. 41.

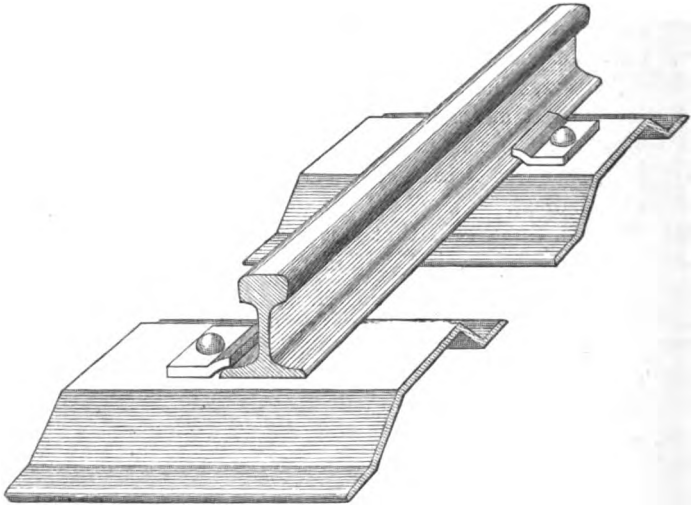


Belgium for some years, but not on the same gauge as that of the English lines. Mr. Le Grand, who had great experience with wrought-iron sleepers, having devoted his attention to the subject for upwards of twenty years, and had manufactured more than 5,000 miles of wrought-iron railway sleepers, chiefly in connection with mines, and some for the ordinary gauge, was present, and had deputed him to say a few words on the subject. Mr. Le Grand's sleeper though similar to Mr. Webb's, represented in Fig. 41, was

Digitized by Google

Mr. Shaw. not exactly like it, as it was made of one piece of iron only, which was closed up while hot by a machine for the purpose. There were either two or four rivets, one or two on each side. This chair being riveted to a "Vautherin" sleeper, it was found to be exceedingly efficient, particularly in mines, where the Vautherin iron was replaced by worn-out rails, which then served as sleepers. Mr. Le Grand's favourite system, however, was that of a sleeper entirely of one piece. His permanent way consisted of only the rail and the sleeper, or, properly speaking, two sleepers, because, as would be seen from Fig. 42, there were sleepers which clipped the rail outside, and sleepers which locked the rail inside. The

FIG. 42.

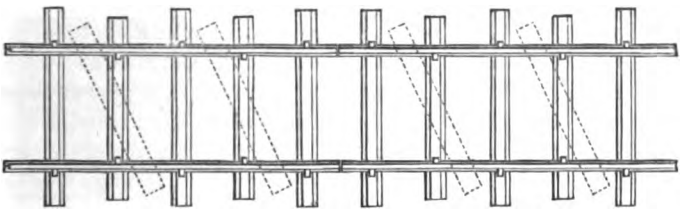


clips were riveted on to the Vautherin section of iron by means of one heavy square rivet, the inclination to the rail of 1 in 20 being given by the cant of the sleeper. It would be seen that this was a perfect fastening, without bolts, nuts, or keys, and he thought that was the nearest approach to a permanent way. The only tool required to secure the road was a hammer to bring the inside locking sleepers into place, as in Fig. 43. He did not speak of the 17,000 miles of railways in England, or the 100,000 miles of railways in the United States. The cost of repairing the lines in England was a question for the engineers in charge, who knew, doubtless, the best way to satisfy the shareholders and the public. He referred particularly to lines in Australia, New Zealand, India, and Turkey. It was stated in the Paper that a sleeper

Digitized by Google

for the 4 feet 8½ inches gauge ought not to weigh less than 90 lbs., and to have as few loose pieces as possible. Mr. Le Grand's sleepers weighed 90 lbs., their length being 8 feet 2 inches and 7 feet 8 inches, the cost 6*s.* for a 4 feet 8½ inches gauge, and they had no fastenings. Taking two thousand sleepers per mile, the weight was 81 tons, as against 170 tons measurement for two thousand wooden sleepers 9 feet by 9 inches by 4½ inches. Since he had commenced business Mr. Le Grand had made about ten million sleepers, and many of those supplied by him twenty years ago were still in a good condition, a fact which dispelled any idea of dangerous corrosion. There were two thousand large sleepers on a railway in Belgium which had never been touched Mr. Shaw.

FIG. 43.



Scale ¼ inch = 1 foot.

since they were laid in 1877. In that year the Indian Government asked for specimens of all kinds of permanent way; many were sent in from various quarters, and there was some of the old iron at the India Office now. He did not think that much came of it, and certainly none of the systems presented were adopted. At the time referred to he saw a gentleman connected with the Indian railways, and said he thought he had a system which would answer the purpose. He was then asked, "Has it been down ten years?" and he replied, "No." He was also asked, "Have you ten thousand sleepers laid anywhere?" and he replied, "No." "Then," said the official, "it is useless to come to me." That was very much the story that all gentlemen had to tell with regard to any improvements they proposed.

Mr. J. LIVESEY said that on the occasion referred to his system of sleeper was adopted for the Indian States Railway, and a large quantity ordered. Mr. Livesey.

Mr. RUSSELL SHAW was aware that Mr. Livesey's sleeper had been ordered, but he did not know that any specimens had been sent to the India Office. He had thought that it was not necessary for Mr. Livesey to send his sleeper anywhere, because it was so well known. Mr. Shaw.

Digitized by Google

Mr. Bergeron. Mr. CHARLES BERGERON said that he had attended some experiments conducted by Professor Willis, of Cambridge, on the flexure of rails on the passage of trains running at great speed, at the meeting of the British Association at Birmingham in 1849. Similar experiments had been made before that date at Portsmouth by Sir Henry James, R.E., and Captain Douglas Galton. Two light rails were laid upon two solid supports distant several feet from each other. A heavy vehicle standing at the middle of the rails produced a depression of about ½ inch. The same vehicle, descending an incline and running over the light and flexible rails, forced them down four times deeper, or about 2 inches, not at the middle of the rails, but at two-thirds of the distance from the point at which it entered upon the rails. The tendency of the vehicle, obliged to mount over the remaining distance, was to jump and leave the track. The conclusion drawn from that experiment was that, for obtaining a solid permanent way, it was necessary to employ rails not subject to bend, or to have the supports close to each other. According to Captain Douglas Galton, under a line of rails 30 feet long, American engineers had put sixteen sleepers, the distance between two adjacent supports being less than 14 inches. Under such conditions the permanent way of the Pennsylvania Railroad was so firm that the manager proposed to run express trains at a regular speed of 60 miles an hour.

In the present state of railways, the successive sleepers or supports of the rails did not present the same amount of resistance to the vertical pressure of the trains. On the railways with wooden cross sleepers, as used generally in Europe and in America, the longitudinal system of permanent way might be considered as pyramids of compressed ballast, the intervals between those pyramids being filled with porous ballast, presenting no resistance to the horizontal displacement of the sleepers. Rain-water percolated freely through it. Gradually particles of sand filled the interstices; the water did not escape, the pyramids of compressed ballast which supported the sleepers lost their consistence, began to sink, and required fresh packing. The engineer of one of the principal railway companies in France had given him as a definition of the maintenance of the permanent way, that it was a continual fight between the engine drivers and the platelayers.

In walking along a line open for traffic, upon which trains ran at great speed, the sleepers would be observed to undulate according to the oscillations of the rails. It might happen that several consecutive sleepers sank deeper than those between which

Digitized by Google

Mr. Bergeron.

they were included. In that case the rail was supported by two chairs at 9 or 10 feet distance, and under the pressure of a heavy locomotive running at a speed of 60 miles an hour it could not preserve its rigidity. It bent exactly as the flexible bars in the experiments of Professor Willis to which he had referred. The locomotive which ran over it had a tendency to jump and leave the way. In his opinion the greatest number of instances of trains leaving the line were produced in that manner.

After an accident on the Midland Railway last year, Colonel Yolland made the remark that accidents of that sort were more frequent upon lines where the sleepers had been newly packed, than on those which had not been repaired.

He was not disposed to believe that the permanent way with iron sleepers was able to resist the destructive action of trains running at great velocities. In his opinion its solidity depended in great measure on the comparative amount of its dead weight. The Author did not mention the weight of the iron cross sleepers used on the North Eastern Railway at Middlesbrough. He supposed they were lighter than those of wood. They would move horizontally under the pressure of trains at great speed more easily than the latter. For that reason he believed the road with the double-headed rail, as generally employed in England, was more stable than the Vignoles rail used on the Continent. With cast-iron chairs, which weighed about 40 lbs. each, every sleeper was embedded deeper in the ballast in proportion to the thickness of the chair; its dead weight was increased to about 80 lbs., and it would be much more difficult to move them than the others.

He agreed that one of the best kinds of ballast was small broken stones or slag. Calcareous broken stone, from the deep cuttings in the Jura and the Pyrenees, was used in large quantities in France for ballasting the lines of the Paris, Lyons and Mediterranean and of the Southern railways. The permanent way was better supported with such ballast than with sand; but it had less elasticity, and the wood was more exposed to decay by the action of humidity and air circulating freely through the interstices of the broken stones than when embedded in sand. The packing of the iron sleepers with broken stones 2 inches thick did not appear to him very easy, and he did not see how it was possible to secure uniformity of resistance for the sleepers when there were no means of ascertaining the quantity and the density of the ballast underneath.

After many trials, and many years of study and observation, he

Digitized by Google

Mr. Bergeron. had arrived at the conclusion that the problem of the best permanent way could be solved by the application of two principles:—

1st. Ballast of sand, instead of being spread in a loose state over the formation of the railway, ought to be embedded in it and compressed by rollers, like the broken stones of a Macadam road.

2nd. The sleepers, of wood or iron, instead of being packed with ballast caulked underneath, ought to be sunk into the compressed sand, or ballast, in the same manner as piles support the foundation of an edifice were sunk in the ground.

In the early period of railways, the rails were attached to blocks of stone lying on sandy ballast. It was a great mistake to treat wooden sleepers in the same manner as stone blocks, and to bury them in a stratum of loose ballast, 2 feet thick, above the formation of a railway. The wooden sleepers ought to rest upon a solid foundation, and engineers had begun to understand this, as they showed by advising that broken stones should be substituted for sand or fine gravel for ballasting railways. He had observed that the most steady parts of a railway, upon which trains ran with smoothness, and never got off the way, were long viaducts or bridges, on which the rails rested upon longitudinal wooden beams laid to an accurate gauge, on the iron girders of the viaduct. There was no flexure of the way, no tendency to derailments; the wood possessed sufficient elasticity to protect the iron girder against the destructive pressure of heavy trains rolling at great velocity. A similar reason had induced engineers to apply the Mansell wheels, with wooden centres, as cushions to counteract the pressure of the tires in contact with the rails. He had always been in favour of rails bearing upon wood. He thought the wood ought to rest upon ballast equal in rigidity to the iron bridge girders. For that reason he proposed to put the ballast in cuttings or ditches made in the formation of the railway, and to compress it with heavy rollers exactly as those used for metalling Macadam roads. There was no danger of having the fine ballast or sand of the railway turned into mud, because the rain-water could not percolate through it. It was the same with good Macadam roads; any rain falling upon the surface flowed over without penetrating the road. It would be the same with railways ballasted in the manner which he proposed.

More than ten years ago he offered to renew the permanent way of the Northern Railway of Spain between Madrid and the Escorial. The ballast on that section was quarry sand, rather

Digitized by Google

Mr. Bergeron.

clayey, through which rain percolated with difficulty. Although in that country rain was not frequent, and the permanent way was in tolerable order, it happened occasionally that it was dangerous to run trains at great speed after rain. The railway was then covered with water, and the ballast, being very muddy, could hardly support the weight of heavy trains. To remedy this state of things the engineer of the railway had made cuttings across the line at every joint of the rails, and had filled them with broken stones, so that the water between the rails was able to escape through the interstices between the stones. The three sleepers at every joint of the rails, lying on the stones, did not move much at the passage of the trains; but the others sank in the muddy ballast, and the road was exposed to great springing which prevented its being travelled over with safety by rapid trains. He observed that this circumstance produced a singularly destructive effect on the rails. They were put out of order not as was generally the case, by the friction of the wheels, which had a tendency to grind off the surface of the metal, but by frequent bendings and deep oscillations of the rails, the iron pile, composed of different seams of iron compressed together in rolling the rails, had those seams unwelded, and long ribbons of iron could be easily detached from the rails by hand.

On the 27th of January 1873, he addressed to the board of directors of the railway a report describing a new sleeper and a new mode of laying down the permanent way of the section from Madrid to the Escorial. In his report, he had described the advantages of the sleeper.

1. The bottom of the Vignoles rail was maintained by the sides of the cutting made in the vertical iron bar; it could not move, and the accuracy of the gauge was perfect.

2. The rails lay upon wood, which was preferable to the metallic surface of iron sleepers on account of its elasticity.

3. The blocks of hard wood, principally of green oak trees which grew in Spain, and were cut only to be burned as firewood, would be found in abundance on the spot, and were to be bought at a very low price.

4. Such short wooden blocks could be creosoted or pickled more easily and at much less expense than large sleepers.

5. After many years, at least double the life of an ordinary sleeper, these blocks might have to be replaced—an operation that could be done at a low price, because the vertical cross-bars, the bolts, and the nuts and spikes could be used again with new blocks.

Digitized by Google

Mr. Bergeron.

6. In the curves, the gauge could be easily widened with a file, a chisel and a hammer, by enlarging the cuttings of the bar on the spot.

7. When a train ran off the line upon a permanent way supported by iron sleepers, these were completely ruined and could not be repaired; with the composite Spanish sleeper the common iron bar could be dressed and forged at any smith's shop.

8. The usual iron sleepers must be made of steel or wrought iron of the best quality, and could be rolled only in the large ironworks of England, Belgium or France. A quadrangular bar, as the one for the composite sleeper, could be obtained in every town of Spain.

When he proposed his scheme to the Spanish engineers, he had not thought of changing the ordinary manner of making the permanent way, by laying it upon a thick deposit of loose ballast spread on the formation of the railway. It was in the ballast itself that he proposed to make the ditches, to be filled afterwards with broken stones at the bottom and sand on the top, in which the wooden blocks were to be rammed, and were to act as the stone blocks of the first railways. He had come to the opinion that ballast simply spread over the formation of a railway had not sufficient cohesion to resist, without fear of derailment, the high velocities that trains in future would be likely to attain.

Obviously particles of ballast which were not inclosed in frames and surrounded by supports, would be displaced and move and roll in every direction, both from atmospheric causes and from the shaking and concussion of the passing trains. That evil must be prevented. He had ascertained from experiments on the Swiss railways, of which he took the management by contract twenty years ago, that the lines on which the ballast was embedded in the formation, as the broken stones used for metalling Macadam roads, were more easily and more cheaply maintained than the others.

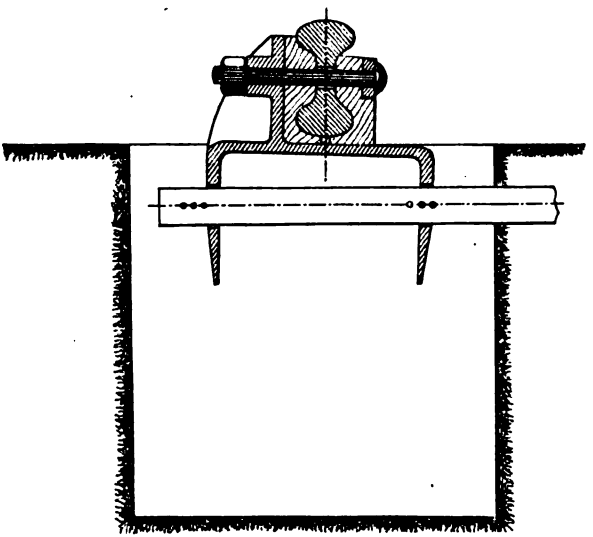
He had at the same time conceived the idea of a new iron sleeper and system of permanent way (Fig. 44). In this, every sleeper was composed of two troughs in cast or wrought iron, tied at each end by cross-bars maintaining them at the required gauge. The troughs were 2 feet long and 10 inches wide. The vertical sides had a sharp bottom-edge to facilitate their penetration into the compressed ballast. The top of the trough was inclined $\frac{1}{20}$ according to the usual cant of the rails. The cross-bars passing through the four vertical sides were tied to them by bolts which maintained the gauge accurately. The trough was surmounted by a longitudinal jaw against which the rail was supported as

Digitized by Google

by a fish-plate, and was tied to it by three bolts and spring nuts. Mr. Bergeron.

The rails would be pierced at the works with the proper holes for the bolts which tied them immovably to the jaws of the troughs. The joint of two rails occurred at the middle of a trough, and a single bolt held both ends tight. The distance between two consecutive sleepers being no more than 1 foot, the rail, strongly

FIG. 44.



attached to the jaws at the extremities of the troughs, would not appreciably bend, even under the heaviest locomotives. In the formation of the roadway, and under each line of rails, two ditches would be dug 18 inches deep, 18 inches wide at the top, and 15 inches at the bottom. The ditches were to be filled with sand mixed with an equal volume of water. The molecules of sand carried by water filled the interstices of the earth in which the ditches had been dug. Gradually the sand acquired greater density and became impervious to water. Before it was quite dry it was submitted to the pressure of a heavy cast-iron roller, which transformed it into a soft sandstone, into which the two vertical blades of the trough could easily penetrate when properly sunk by a rammer, and at the same time were able to support, without sensible alteration of form and volume, the weight of any large mass standing or rolling over it. It was in such walls that the

Digitized by Google

Mr. Bergeron. troughs were sunk; they would be struck by a rammer till the plate at the top lay evenly on the sand wall and could not be driven deeper. In that condition, the rail was laid on the trough and strongly bolted to it. The permanent way was then in order. The sleepers could not sink; and the trains drawn at the highest speed by the heaviest locomotives would roll over it like sledges upon a frozen lake, derailment becoming almost impossible.

Mr. Rawlinson. Mr. R. RAWLINSON, C.B., said he scarcely need tell railway engineers that one of the worst foundations for a railway would be a hard base. That might seem paradoxical, but it was a fact, and an engineer who wished his road to be smooth in running, and to be enduring, would have an elastic foundation. The road across Chatmoss was perhaps more easily kept in repair than any similar length of line in England, because it was elastic throughout. He could recollect very well the commencement of railway making, and he remembered when stone blocks were placed upon the hard bottoms of the cuttings. It was well known what came of that. At great risk they had to be removed. He was old enough to recollect a much more absurd arrangement, when one of the greatest engineers in another department was called upon to design a line of rails, and was so particular to have a rigid foundation that he brought up rubble sleeper walls through all the embankments, in some instances even from a depth of 60 feet. The entire length of line was thus made with stone sleepers and with Vignoles rails. The consequence was that when the carriages ran over the line, the vibration was most annoying. Road-makers also knew well that a rocky foundation was most destructive, unless they got rid of the jar by cutting the rock away and putting in a certain depth of intermediate ballast. He did not think that any engineer who was practically engaged in making and maintaining railways would seek to obtain even an approximately solid foundation for the sleepers. He would rather seek an elastic foundation, such as fine gravel would give, one that he could easily manipulate in raising and packing the sleeper. He would be contented with that, and would shun anything approaching to a permanently solid base; for wherever such arrangements had been made, they had proved a failure. On the Great Western railway, for instance, where piles had been put across the embankments underneath the ends of the rails, they had to be cut off in order to restore the line to a workable condition. Railway engineers now knew by experience that the rails and sleepers lasted longer upon the embankments than in the cuttings; and, inferentially, that the rolling plant also lasted longer.

Digitized by Google

Mr. W. MARTINEAU said he thought that every engineer who had had experience in materials in tropical climates would welcome any system which should combine sufficient durability and strength with economy and lightness. It was well known that all timber, even the best, decayed in tropical climates with a rapidity unknown in this country; and the transport of materials was also a very serious matter. Engineers therefore sought especially for lightness and sufficient durability. It was not a question of solidity such as that required for railways with the enormous traffic of the lines in England. He could not agree with the statement that the corrosion of iron sleepers and iron permanent way was almost nil; it might be so in this country, but it was not so in tropical climates. Of course the conditions specified by the Author of perfectly dry ballast, good drainage, and the like, might ensure, even in tropical climates, a greater durability for the permanent way, but that could not be the case when a new line was being constructed. He had seen a great deal of material used in tropical climates, and his experience was that even iron decayed with great rapidity, varying according to the soil. The soil itself no doubt contributed very much to it, and the heat of a vertical sun upon the surface of a wrought-iron sleeper in many soils, especially where there was much vegetable matter, as in tropical forests, generated acids which acted rapidly upon the iron. It was highly desirable, therefore, that wrought-iron sleepers sent to hot climates should be protected by the best possible means. With regard to the end-shifting of sleepers, it was possible that the curved form of sleeper might to some degree prevent that effect, but he agreed with what had been stated as to the necessity for the end-turning or for a web in the centre to prevent movement, because in lines in undeveloped countries and in mountainous districts curves were employed which were not known in this country. On sharp curves and steep gradients the pressure on the outer rail was very great, and anything which would prevent the end movement arising from that would be desirable. He thought that very good fish-plating presented a resistance to end movement. He exhibited some photographs showing what a good fish-plated line would stand. They represented a railway in the north of Chili, in a district supposed to be almost rainless. Last year heavy floods occurred, and embankments and bridges had been washed away, but in every instance the rails formed suspension bridges over chasms from 300 to 500 feet in width. Mr. Martineau.

Mr. W. A. DAWSON said he thought there was one disadvantage in the cross sleepers and fastenings of Mr. Le Grand's system. It Mr. Dawson.

Digitized by Google

Mr. Dawson. appeared very simple and good, but he believed that after the line was once laid and packed, when it became necessary to replace a rail, the ballast would have to be disturbed; to get a rail out it would be necessary to twist one of the sleepers sideways, and this would entail the removal of nearly the whole of the ballast up to the next sleeper. That appeared to be a serious disadvantage, which, on a line where the traffic was considerable, would render it almost unavailable.

Mr. Shaw. Mr. RUSSELL SHAW replied that that was the disadvantage, but the work would only have to be done once in every twenty years, or as often as the rails were worn out.

Mr. Dawson. Mr. W. A. DAWSON remarked that where the traffic was considerable the rails would not last twenty years.

Mr. Allan. Mr. G. ALLAN was afraid that the impression conveyed by the Paper would lead to the opinion that English engineers were behind the times in the matter of iron permanent way, as compared with Continental engineers. That certainly was not the case. English engineers had been the first to enter upon the subject of iron permanent way, and they had been conversant with it during the past twenty years. In India iron permanent way had taken the form of pot sleepers, bowl sleepers, and others of different type, but on the same principle, and the system had worked satisfactorily. Mr. Livesey had been one of the pioneers, and his sleeper had always been considered satisfactory. The type which had been preferred by English engineers was the pot sleeper, which he thought might be more properly called the chair sleeper; but there was no doubt that that form had many advantages over the longitudinal or transverse sleeper. He knew from conversation with Belgian engineers that they considered the Hilf longitudinal system rather objectionable. It was difficult to pack and maintain the ballast under it; the blows of the engine indented it; and it was impossible for the platelayers to take out the indentations or waves, so that the line became crooked. The pot sleeper had the advantage of being very readily packed. Greaves's sleeper had a couple of holes in it, and could be packed on the top; and the others were so shallow that they could also be easily packed. There was no doubt, however, that a flattish bottomed sleeper had an advantage over the pot sleeper if it had such a depth at the ends as Mr. Bruce had mentioned. Unquestionably vertical ends or flanges were preferable to any rounded surfaces. As the result of some years' experience, it appeared to him that iron surfaces were objectionable, all things considered. For high speeds the question of iron sleepers had

Digitized by Google

not been touched in England, simply because timber continued to be cheaper in first cost. That was not the case on the Continent, where the shoe pinched more tightly. Unfortunately, however, Continental engineers had not profited by the experience of their brethren in India, otherwise they would never have adopted the transverse or the longitudinal sleeper. Mr. Webb had adopted a sleeper that would no doubt answer. Something was required which was more economical both in first cost and in maintenance than either the transverse or longitudinal systems. In England, on lines of high speed, something more substantial and durable was required. Light sleepers would be knocked to pieces, the engines would get off the roads, and the wagons would be soon destroyed. After the introduction of the pot sleeper, the breakages in India had been so enormous that wrought iron was insisted upon, and now that was being gradually superseded by steel. No doubt with a good steel sleeper there was greater durability than with either cast or wrought iron. The style of sleeper which had suggested itself to his own mind was one with a good wooden cushion combined with iron. It had been approved by the engineers of the Metropolitan and Metropolitan District Railways, and engineers of such lines would not consent to make a trial of a sleeper on their main roads for the first time unless there was something substantial and good about it. Unfortunately the price of iron became so high that the system was not carried out. A period had now been reached in England when engineers would certainly have to take up the question of steel sleepers, and devise some system of combining sleepers and rails in such a way as to present an elastic road. It would be a question whether the interposition of a good wooden cushion would not be more advantageous than having two metal surfaces in contact. Mr. Allan.

Mr. Ernest Benedict observed that in 1877 he had read a Paper on metal sleepers for railways before the Institution of Engineers and Shipbuilders in Scotland,[1] and his four years' experience since that time had confirmed the opinion therein expressed, that, under certain circumstances, it was impossible to improve upon a cast-iron bowl sleeper if it were of a proper shape and properly maintained. He understood from Mr. Leslie that there were nearly half a million iron sleepers on the main line of the East Indian Railway, which could hardly be called a line of small traffic. Mr. Benedict.

1 *Vide* Transactions, vol. xxi., p. 105.

Digitized by Google

Mr. Arrow. Mr. J. T. ARROW said that only wrought-iron sleepers had been mentioned as having been actually employed, but that since 1874 steel sleepers had been used on the Oude and Rohilkund Railway, and had answered most satisfactorily, the amount of repairs being absolutely nil. The sleeper was formed of steel $\frac{3}{16}$ of an inch thick, and was stamped into a pot 6 inches deep with corrugations round the sides which were found to increase the strength considerably: the sleeper weighed 33 lbs. The rail was held in position by three clips, two of which were riveted, the third being held by nut and bolt. A Sterne's washer was interposed between the nut and the flange of the rail, which prevented its being shaken loose; £100,000 worth of those sleepers had been sent out, and there were large orders still uncompleted. The rail used was of the Vignoles pattern. The sleepers gave a bearing surface of about 4 square feet each. The road was not too rigid or too elastic, and the wear on the rolling stock had been considerably reduced since that form of sleeper had been adopted. Four different kinds had been tried—two of wrought iron, one of cast iron, and one of teak, all of which had been given up and were being replaced by steel. The cost of the steel sleepers was about the same as that of wrought-iron sleepers. The cant of the rail was effected by the tie-bar and the position of the holes or slots in the sleepers. When the sleepers were stamped, the holes to receive the tie-bars were both punched while they were in that position in order to ensure similarity in every sleeper. The sleepers were fastened together by means of gib and cotter; and with these connections they never shook loose. The gib was fixed in the tie-bar by means of a recess, and it could not be shaken out. The cotter was a split one, and that prevented any movement. By means of the recess in the gib, a variation of gauge to the extent of $\frac{1}{2}$ inch could be obtained between the sleepers. The plan of laying the rails direct by a rigid tie-bar independent of the sleeper had been found to answer better than passing the tie through the sleeper.

Mr. Wood. Mr. C. WOOD, in reply, desired to make one or two remarks on the drawings that had been hung upon the wall. With regard to the design by Mr. C. Bergeron (Fig. 44), he might mention that a similar plan had been described in the volume of Proceedings of the Institution for 1857, except, perhaps, that the tie-bar and fastenings were a little different. He was aware that many of Mr. Le Grand's sleepers had been used in collieries during the last fourteen or fifteen years. Some of them, from Earl Durham's collieries in the county of Durham, had been taken out only a short

Digitized by Google

time ago and weighed, and after fourteen years' use in the mines, they had only lost ½ ounce. That was a pretty good criterion as to the question of corrosion in a damp atmosphere. Practically the sleepers were as good as new. Reference had been made to the turning down of the ends of sleepers to prevent end shifting. He had before him a model showing two sleepers—the English sleeper (Fig. 45), 9 feet long, and the Continental. The Continental sleepers were from 6 feet to 6 feet 9 inches, the largest being about 7 feet long (Fig. 46). If these short sleepers were watched as a train was going over them, it would be seen that the end worked considerably. The hammering of the wheel over the rail knocked the ballast down under the rail, and it was also pitched out away from the ends. Practically there was no bodily end shifting. The idea had arisen in former times through bad fishing, and through an insufficient outside bearing of the sleeper. If the joints in the rails were moderately tight, and a good sized sleeper was put down, no end shifting would take place. Where

Mr. Wood.

FIG. 45.

FIG. 46.

a short sleeper was used, something was wanted at the end to keep the ballast from working. Immediately under the rail, whether it was of wood or iron, there was a vacant space, and in this respect Mr. Livesey's sleeper was worse than the Continental sleeper.

An end without resistance, or with lines of least resistance to prevent shifting, would somewhat resemble the breast of a plough, as represented by Mr. Livesey (Fig. 27). Evidently there must be a hollow underneath—on account of the compression of the ballast—and as the wheel passed over the rail it would pitch the ballast off the top towards the end; and this being clearly the case (Fig. 46), he wished to know what end resistance there could be there, and what was therefore the good of the complicated, turned-down end? There could be no doubt that a short-ended sleeper, such as he had described, must be a bad one. Fig. 28 showed the effects of a good, wide-spread sleeper with outside bearings, and of a short one, as also Figs. 45 and 46. The longitudinal sleeper, the

Digitized by Google

Mr. Wood. bowl, and the short sleeper, all came under one category. The bowl sleeper was nothing more than a longitudinal sleeper cut up into pieces. They were all far better than the short-ended sleeper. The hammering of the rail over the longitudinal sleeper caused a uniform subsidence in the ballast immediately under the rail, while, on the contrary, in a short sleeper the ballast was hammered away under the rail; thus causing a riding on the ridge in the centre between the rail (Fig. 46). That was why it was said on the Continent that some of the short sleeper railways were worse to ride on than the longitudinal. With the longitudinal system there was a general subsidence uniformly all the way along, whereas the short sleepers rode on the middle ridge between the rails, and as they travelled along the carriages and engine pitched and rocked from one side to the other, there being nothing to steady them. With regard to the long-ended sleepers he thought that Mr. Webb and he were the only persons who had availed themselves of the experience of English practice. To get a good, steady road for quick travelling, there must be a long sleeper. The strains upon the sleeper were completely reversed. In the case of the short sleeper there were strains of tension on the top, and a compression on the lower web, because there was no outer support; but the ends of a 9-feet sleeper extended beyond the zone of disturbance of the ballast from 1 foot to 15 or 18 inches and outside that zone the sleeper took the bearing (Fig. 45), the strains on the sleeper thus became completely reversed, the tension being on the foot. That was no mere theory; it could be seen on looking at the sleepers on the North Eastern Railway and at Mr. Webb's on the London and North Western Railway. It would be observed that in all cases the ballast had more or less given way through the elasticity of the sleeper immediately under the rail, but outside this zone of disturbance the ballast lay unmoved. The sleeper had thus three good bearings, the two outside ones for steadiness of travelling being the most important. The support between the rails was done away with, and the value of the bearing surface upon the ballast was more than doubled (Figs. 45 and 46), which conclusively showed the value of the long sleepers over the short, and also showed the fallacy of the turned-down end theory. A further proof on this point was supplied by Mr. De Bergue's plate sleeper, thousands of tons of which had been in use for thirty years, and of which during the last two years the Author had made several thousand tons more. Engineers in Spain, where they were in common use, surely would not go on ordering them

Digitized by Google

year by year if they found them shift. Again, large quantities of the Denham-Olpherts sleeper (a modification of De Bergue's plate-sleeper) were being sent out to India at the present moment, and had been sent for several years; therefore no importance could be attached to the end shifting theory by the Indian State railways engineers. Mr. Bruce had mentioned that on the North Eastern Railway several of the sleepers had broken. Many of the sleepers employed were made of puddle bars, and had cracked through the lower web, and the ends had what the platelayers called "cocked up." That was the effect of what he had been explaining. The ballast had given way under the rail, and the whole weight of the heavy traffic had come on the centre and on the outer ends, so that the strains had been reversed; from a tension on the top it had become a compression on the top, and a tension through the lower web, which had not been quite strong enough; but since this had been strengthened not one sleeper had broken. Mr. Wood.

A length of 2 miles of the sleeper, represented in Fig. 24, had been laid at Middlesbrough. One half was over a sharp curve, over which three hundred and fifty trains per day passed up and down; the traffic over one line of rails alone had amounted to 60,000,000 tons.

It had been stated that some of the iron-plate sleepers in India had replaced and been mixed with the wooden ones. That plan had been tried on the Continent and had failed, because, wherever wooden sleepers had been in use the rails were both out of tilt and out of gauge. If, therefore, an iron sleeper were put in between wooden sleepers the rail would be drawn up tight to gauge, and this would twist the rails in and out. If the old sleepers were bad the road must be completely relaid. The attempt to mix one kind of sleeper with another was a mistake. With regard to the question of corrosion he wished to direct attention to a sleeper that had been in use thirty years on the Bristol and Exeter Railway, which was somewhat corroded. Wherever there had been a loose bolt the heads had nearly worked through. He also exhibited a fish-plate taken off the North Eastern Railway after three years' use. It had been recently removed on account of the heads having sunk deeply into the fish-plate. He likewise exhibited a specimen of the Barlow rail which had been in use twenty-two years, having been laid in ballast in Spain. Two cargoes of rails had been recently brought into Middlesbrough to be cut up and re-rolled, and the specimen was a piece that had been cut out from them. It would be observed that the rail had the scale which was on it when it left the works. The rails

Digitized by Google

Mr. Wood. had been destroyed, the heads worn off, and the ends battered to pieces, but there was no corrosion. He had also a tie-bar, used on the Guisborough Railway, which had been buried twenty-five years, and the scale was hardly off. In some neighbouring works to his own a tie-bar had been buried sixteen years in the ballast, and the scale was on it still. He thought, therefore, that whether in Spain, in England, or in India, there was nothing to fear from corrosion. No one had challenged the simplicity of his sleeper and fastenings. The bars on the North-Eastern Railway which had failed were all rolled lengthways irregularly and badly. The shoulders had been cut away, and Mr. Cudworth showed him one that was taken out which never had any shoulder. When these sleepers were made no machinery existed for bending and cutting the shoulders, and all was done by hand, and by contract. At the present time everything was executed by machinery, since which, in all the lines where the sleepers have been laid, not a single failure has taken place. Mr. Cudworth admitted that the fastenings and keys had held better than any that had ever passed through his hands. He had mentioned the cost in one or two instances, but he had come to the conclusion that it was better not to do so because in some instances the heavier and more complicated forms cost less per yard than some of the more simple forms, the difference depending upon the prices of material and labour. He had, however, recently made a calculation bearing upon that subject. He had avoided any mention of pots and bowls because they were too numerous for his liking, and he thought it would be better to confine himself to the two systems of longitudinal and transverse sleepers.

Thus cast-iron bowls for a 5 feet 6 inches gauge, weighing, with the fastenings, 230 lbs., cost, free on board ship at Middlesbrough, 10*s.* a pair. Adding 2 per cent. for breakages between the works and the place where they were laid, 30*s.* for freight, shipping charges, and insurance, and 20*s.* for inland carriage, all of which were moderate charges, the cost of a pair of pots and bowls would be 15*s.* 6*d.* or £1,364 per mile. The cost of a 5 feet 6 inches wrought-iron sleeper, with a stronger section than any that he had shown as being in use on the Continent, weighing 116 lbs., 9 feet 6 inches long and 9 inches wide, with the clips, including the same charges, was 10*s.* 3½*d.* against 15*s.* 6*d.*, showing a saving of one-third, and this same sleeper would give 1 square foot more area on the ballast than the oval bowls. Taking the round pots and a lighter sleeper for the 4 feet 8½ inches gauge, the price in England was 7*s.* 10*d.*, and for wrought-iron sleepers 7*s.*; in India,

Digitized by Google

COMPARISON BETWEEN the COST of CAST-IRON BOWL or PLATE SLEEPERS and HOOD'S PATENT WROUGHT-IRON SLEEPERS, for DIFFERENT GAUGES. Mr. Wood.

Particulars of Sleepers.	Gauge of Railway.	Weight of each Sleeper and Fastening.	Cost of each Sleeper in England. F. O. B. Middlesbrough.	Percentage added for Breakage before laying down abroad.	Cost of each Sleeper, with 30s. per Ton Freight and 20s. per Ton Inland Carriage.	Weight per Mile.	Cost per Mile abroad, with 30s. per Ton Freight and 20s. per Ton Inland Carriage.	Saving per Mile in favour of Wrought-iron Sleepers.
	Ft. In.	Lbs.	s. d.		s. d.	Tons.	£.	£.
Two cast-iron bowl or plate sleepers, with tie-bar, gibs, cotters, &c. .	5 6	230	10 0	2	15 6	180⅔	1,364	..
One wrought-iron sleeper 9 feet 6 inches long by 9 inches wide, with clips	5 6	116	7 8	..	10 3½	91⅓	906	458
Two cast-iron bowl or plate sleepers, with tie-bar, gibs, cotters, &c. .	4 8½	193	7 10½	2	12 5½	151⅓	1,094	..
One wrought-iron sleeper (for light traffic) 8 feet by 9 inches wide, with clips	4 8½	98	7 0	..	9 2	77	807	287
Two cast-iron bowl or plate sleepers, with tie-bar, gibs, cotters, &c. .	metre	106	4 5	5	7 0	83⅓	616	..
One wrought-iron sleeper 5 feet 6 inches long by 9 inches wide, with clips	metre	65	4 6	..	6 0	46⅔	528	88
One wrought-iron sleeper 9 feet long by 10 inches wide, for heavy English traffic	4 8½	150	10 0	..	..	..	..	..

or in any place where 30*s.* freight and 20*s.* inland carriage were charged, the cost would be 12*s.* 5½*d.* against 9*s.* 2*d.* Again, take the metre gauge laid with plate-sleepers, but in this case adding 5 per cent. for breakages, the difference was 1*s.* per sleeper in favour of the wrought iron, in India. He had assumed the wrought-iron sleeper to weigh 65 lbs., to be 9 inches wide, and $\frac{5}{16}$ inch thick, which for such a gauge and weight of rail was very strong. There was thus a saving of £458 per mile in favour of wrought iron for large sleepers for the 5 feet 6 inches gauge, and £287 in favour of wrought-iron sleepers against the cast-iron round bowls, and for the small metre gauge there was a saving of £88 per mile in India, whilst the railway if laid with long

Digitized by Google

Mr. Wood. sleepers would have increased stability as shown in Fig. 29. There would be no outside disturbance, but a far better sleeper, and a far better road. With regard to packing, he would not say that a flat plate or a flat wooden sleeper might not be more easily packed than the hollow pot or wrought-iron sleeper, but unquestionably when once the iron sleepers were packed they held their position in the ballast better. The plate-layers on the North Eastern line had told him that they did not require the packing that wooden sleepers did; whilst the saving of cost in relaying or laying a new line was considerable.

Correspondence.

Mr. Boucher. Mr. A. BOUCHER stated that trial had been made on the Northern of France Railway, some twelve years ago, of five thousand Vautherin sleepers, but the experiment had been abandoned. Beyond the question of price, which need not be alluded to, the system presented certain practical defects. In the first place the sleepers took little grip of the gravel ballast, doubtless from their being open ended. The mode of securing the rail to the sleeper left much to be desired, and needed the employment of too many parts to keep it in good order. Finally it was proved by a case of a train leaving the line that these iron sleepers greatly aggravated the consequences of an accident by increasing the time it took to put the track in order again. In an accident that occurred in October 1867, the wheels of the carriages which left the line destroyed all the iron sleepers which they touched; this would not have happened had the sleepers been of wood.

Mr. Cudworth. Mr. W. CUDWORTH observed that a length of 2 miles the Author's pattern of sleeper had been laid on the mineral lines of the North Eastern Railway for two-and-a-half years; but they were not doing well owing to faults in construction, which might, however, be remedied. Many of them had cracked in the bottom flanges immediately underneath the rails. The clips which held the rails were wearing rapidly where they had projections bearing against the underside of the sleepers, but these projections had been too small at first. The iron sleepers took a good deal more packing than wooden sleepers, as the consolidated ballast within the sleeper had to be broken up. In other respects the sleepers answered very well. They were easy to travel over, and the keys were kept well in place by the clips.

Mr. Demoly. Mr. A. DEMOLY contributed, through Mr. Suquet, Traffic Manager of the Algerian lines of the Paris, Lyons, and Mediterranean Rail-

Digitized by Google

way Company, some particulars of the Vautherin sleepers used in Algeria, between Algiers and Oran. Mr. Demoly.

In 1867 and 1868 the Paris, Lyons and Mediterranean Company obtained from the Fraisans Works one hundred thousand iron sleepers of the Vautherin type. Of these ninety-five thousand were laid, namely in 1867, twenty thousand between Relizane and Perregaux; in 1868, eighteen thousand between Blidah and El Afroun; and in 1869, fifty-seven thousand between Oued-Sly and les Salines. On the last-named section these Vautherin sleepers had worn very well, and had given satisfactory results. The same applied to their use on the other sections as far as regarded straight lengths, but in curves the fastenings had given much trouble. The rails had a tendency to overturn outwards, and the gauge easily spread, which necessitated the renewal of the sleepers, and entailed greater maintenance than in other parts. The total number of sleepers renewed from the opening of the three sections of line above mentioned to the end of 1881 had been only two thousand one hundred and thirty-eight, or 2¼ per cent., an average of thirteen years of service. The cause of replacement was generally enlarged bolt-holes, with fissures at the points of contact of the fastenings, and occasionally pronounced cracks at the angles of the sleeper, leading to its deformation.

Among the advantages of the iron sleeper were the following: when coated with coal tar before being laid down, it was not liable to become oxidised; its good resistance to passing weights when supported by proper ballast; the retention of its original shape; and durability when laid under suitable conditions of road-bed and ballast. It was already manifest that on lines of small traffic the iron sleepers lasted twice as long as the best wooden ones, and probably that advantage would be increased. Lastly, they cost little for repairs, in this respect showing an economy of from 30 to 50 per cent. as against wood.

On the other hand they had certain disadvantages. Owing to their skeleton character, they were not adapted to resist lateral movements, which rendered their use impracticable in curves of less than 1,600-feet radius, and defective in larger curves even up to 4,000-feet radius (1,200 metres). For the same reason the system was unsuitable on high embankments, where the incessant vibration tended to shift the ballast from its contact with the under part of the sleeper, and it could only be employed on embankments of small height and perfectly consolidated. But its greatest fault was the unstable nature of the fastenings; the keys worked loose continually; driven home again, they enlarged the holes, and eventually gave way. The inner clips did

Digitized by Google

Mr. Demoly. not secure the foot of the rail firmly enough, and the outer ones easily worked loose and overturned; both indented the sleeper by their friction, and finally cracked it. To sum up, the Vautherin sleeper, good in itself, was destroyed by its fastenings.

A metallic sleeper which Mr. Demoly had designed to fulfil the requirements of traffic in such countries as Algeria, was of iron, of trapezoidal section, with strengthened table, and bent to give the proper inclination to the rail. The attachments were of the simplest, and consisted merely of two clips holding the rail to the sleeper, and two stop-bolts, not threaded, to maintain the tightness of the clips, and allowing, by means of an eccentric washer, of the correct adjustment of the gauge. The saddle-piece of the old system of sleeper, which increased the cost and prevented the use of symmetrical attachments, was suppressed by reason of the inclination of $\frac{1}{20}$ given to each end of the sleeper itself. The additional strength afforded by the cushion of the old type was compensated by an increase of from $\frac{1}{4}$ to $\frac{1}{3}$ of an inch to the thickness of the table of the sleeper, which was thus made of sufficient strength to bear the vibration of the rail and fastenings. At the same time the upper part of the inclined walls of the sleeper was similarly strengthened, to resist the tendency to crack at the angles. The additional thickness thus given allowed of the sleeper being bent as above stated, which otherwise would not be admissible. The Belgian sleepers of ordinary section, bent in the way indicated, without being strengthened, were objectionable. With some other modifications found practicable without loss of solidity, the new sleeper weighed, like its predecessor, 14 kilogrammes per metre (28¼ lbs. per yard). Mr. Demoly submitted that this system presented many advantages. The gaugeward fastening of the rail was exactly similar to its outward attachment, a clip, a plain stop-bolt, a spike giving a progressive squeeze, and fixed by means of the eccentric keyed washer. This mode of fastening gave at once all the results sought in his modification of the Vautherin fastenings. The clip adhered to the side of the rail-foot, and prevented its lateral movement; it also overlapped the rail-foot, thus resisting any shifting of the axis of the rail. In both cases intermittent efforts were transformed into continuous frictionless pressure, above all, without hammering or vibration, consequently the sleeper was not damaged. By the double resistance offered from above and below the sleeper to the overturning of the rail, this tendency was diffused and diminished at the same time that it increased the holding power of the fastenings. Mr. Demoly's system also avoided the inconvenience arising from screw-bolts when embedded in ballast, his fastenings being all plain, and deriving their holding

Digitized by Google

power from the successive helical development of the eccentric washer. An experience of thirteen years had shown that the wear of the fastenings did not affect the sleeper; its only effect was to induce spreading of the gauge. Therefore the advantage would at once be manifest of a system which, by automatically tightening the fastenings at the proper time, prevented the wear alluded to, and thus avoided a source of danger without requiring the frequent provision of new material. His system possessed this merit, and it was certainly not its least one. Mr. Demoly.

Distinct from the question of efficient working was that of difficult replacement of parts. For instance, in the old system the removal of a cushion involved the unfastening of three sleepers and the flexure of the rail, and when the ballast was hard, as frequently was the case, the operation was tedious and difficult. In the new system the clips were easily put in and taken out, and each being independent of its fellows, and not requiring other attachments, the inconveniences alluded to did not exist. Finally, the fastenings being symmetrical, possessed two important economical advantages, viz., the ability to obtain large numbers of two or three forms at a lower price than when many different pieces built up the fastening. Also when in service the outward clip had generally the greater wear, which mostly took place at the neck, without much affecting the head. The gaugeward clip, on the other hand, did little work and lasted long; it was therefore possible to change one for the other, and thus entirely save the provision of one part. Recently Mr. Demoly had devised a new fastening which, though identical in principle, was more simple, and obviated some inconveniences in the manufacture of the earlier fastenings. This improvement reduced the pieces to two, a clip and a cotter, the latter driven in like the spike formerly used for wooden sleepers. It exerted great pressure, and kept the rail so tight, that it might be adopted on lines of the heaviest traffic.

Mr. H. Elworth, Engineer-in-chief of the Swedish Government Railways, remarked that so long as wooden sleepers could be bought at 1*s.* 4*d.* each, the present average price in Sweden, iron permanent way was not likely to come into use in that country; this could scarcely happen until the price of wooden sleepers rose 50 per cent. Mr. Elworth.

Mr. Francis Fox, of Bristol, remarked that the best and most satisfactory of the sections of Macdonnell's, or rather Adams's, system had not been given in Figs. 3 and 4. It was the one with the rib beneath, shown by Fig. 4 in his Paper of 1861.[1] This Mr. Fox.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 268.

Digitized by Google

Mr. Fox. form proved much stiffer than the sections previously adopted; and the joints of the bearers were also fished with angle-iron fish-plates, and the rail-joints were stiffened by the tee-plates shown in the diagram. This system had been but a short time on trial when his Paper was written, but if he had extended the length of iron permanent way, it was the one which, with some slight modifications, he would have adopted. Its invention was claimed by Mr. W. B. Adams, and a royalty on it was paid to him. He believed that a length of Vignoles rails was laid experimentally upon this section of bearer, the rail joints being fished, in place of the joint plates with middle web (which would obviously be inadmissible). If this were so, the system, with the addition of the pine packing, would, in his opinion, have some advantages over Hilf's.

Mr. Hammett's statement of the present condition of the Macdonnell iron way was of course entitled to more consideration than his own views. He could not, however, fully agree with the strongly unfavourable opinion of the iron way expressed by Mr. Hammett. The Bristol and Exeter Railway, upon which it was laid, was under his charge up to the early part of 1876, and he did not recollect any considerable number of cases of breakage of sleepers during the fifteen to twenty years of trial. The tendency of the nuts to work loose was, however, a serious defect. He tried double nuts, and employed various other contrivances, without much result. Another defect was that the heads of the bolts, underneath the bearers, wore the latter into hollows, and that caused an unsteadiness of the hold of the bolts. The resilience of the wooden packing, when first laid, tended to keep the bolts tight, but after it had become compressed by the traffic, this ceased to be the case. The bolts of the De Bergue system (an experimental length of which was laid on the Bristol and Exeter Railway) where the rails rested directly upon the cast-iron oblong bearing plates, did not work loose. This might have arisen from the fact that the bolts held down clips, which bore upon the flange of the Vignoles rail used. The Author was not quite correct in supposing that he considered broken stone ballast preferable to cinder or gravel for this kind of permanent way. He used the cinder ballast because he thought it less likely to crook the bearers than the rougher and coarser material of broken stone. Mr. Hammett, however, had found that broken stone made a better ballast than cinder, even for the iron way. No doubt it was a severe test of the iron way to turn the broad into a mixed gauge permanent way; and if the mixed gauge were likely to be extended, or permanent, it would be a strong argument in favour of transverse sleepers, whether of iron or timber, both as regarded

Digitized by Google

efficiency and cost. He agreed with the Author that the corrosion of the iron bearers, which appeared to have taken place more rapidly during the last five or six years than previously (or else possibly it had not been carefully noted earlier), was due to a large extent to the cinder or clinker ballast. It was always found that the parts of fang bolts buried in the clinker ballast, corroded rapidly. There appeared no reason why the Macdonnell bearer should corrode in ordinary ballast more than the Barlow rail, and some of that had been laid for more than thirty years and was in good or fair condition now. He had never been, in the smallest degree, pecuniarily interested in the success of the Macdonnell iron way. He laid it as an experiment, from a conviction that it was highly desirable to find a durable substitute for the perishable timber rail-bearers in general use. He did not, however, consider it expedient to lay an additional length of iron way subsequent to 1860, partly from the difficulty experienced in getting manufacturers to roll the section of sleeper to which he had referred, at a moderate price, and partly because he felt that only a long and careful trial would determine the relative merits of iron and timber permanent way. With all its admitted defects, the fact remained that the different sections of Macdonnell way had been in use on the Bristol and Exeter line for a period of between twenty-one and twenty-eight years; that some of the fastest express trains in the world ran daily over it, and that the Great Western Railway Company, to whom the line had belonged since the end of 1875, had not found it necessary to remove it and replace it with a timber road. Mr. Fox.

Mr. A. Garet gave the following particulars of the trials of iron permanent way on the Paris, Lyons, and Mediterranean Railway: Four types were employed, viz. Ménans', PLM,A, PLM,B, and Brunon's. They were all adapted to the Vignoles rail. Mr. Garet.

A length of 800 metres of Ménans' sleepers, single track, which was similar in most respects to PLM,A, was laid on the line from Besançon to Bourg, six months before its opening on the 1st of August, 1864. These sleepers, situated between the Byans and Torpes stations, were taken up in September, 1872.

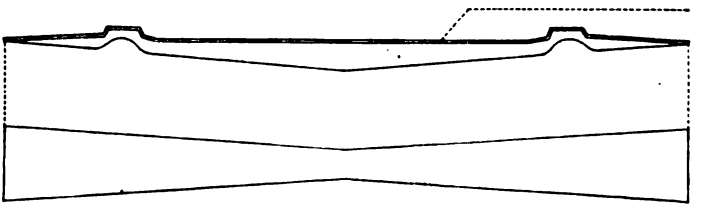
Two lengths of PLM,A were laid in the latter months of 1866 and the beginning of 1867 on the line from Paris to Dijon. The first was 2,000 metres of single line on track 2 between Maison Alfort and Villeneuve St. Georges. It was taken out between the 1st of January and the 31st of May, 1870, on the occasion of substituting steel for iron rails. The second length, 1,500 metres, was double track between Malain and Velars stations. It was

Digitized by Google

Mr. Garet. removed, under similar circumstances, between February and May, 1869; 3,000 metres of PLM,B (single line) were laid on the Grasse branch when under construction, between the stations of Monans Sartoux, and Grasse. This little branch was opened 13th November, 1871, and the iron sleepers were removed towards the end of 1872.

Of Brunon's sleepers (Fig. 47), five hundred, viz. one hundred and seventy-two of steel and three hundred and twenty-eight of iron, were laid on the main track at the Rive de Gier station in August, 1877. Of the steel sleepers forty-eight were transferred to track 1 of the line from St. Etienne to Lyons, between Rive de Gier and Lorette, in January, 1878; sixteen other sleepers

FIG. 47.



Scale $\frac{1}{10}$.

were laid in May, 1878, on track 2 of the line, from Paris to Lyons, near the bridge across the fortifications of Paris. The weights and prices of these different types were :—

	Joint-sleepers.		Counter-joint Sleepers.		Intermediates.	
	Weight.	Price.	Weight.	Price.	Weight.	Price.
	Kilog.	F. C.	Kilog.	F. C.	Kilog.	F. C.
Ménans' sleeper . .	..	14 00	..	10 60	..	10 50
PLM,A „ . .	54·38	14 00	40·80	10 60	40·54	10 50
PLM,B „ . .	47·14	12 81	36·88	9 75	36·04	9 75
Brunon's „ (steel)	..	..	..	..	32·00	10 00

The Ménans' sleepers laid between Byans and Torpes underwent several modifications, bearing chiefly on the form of the saddle riveted to the sleepers and the mode of attaching the rail to the saddle. In the result they very nearly accorded with the type PLM,A, except that they never had angle-irons riveted underneath as in the latter. These sleepers did not give bad results at first. They bedded easily either on broken stone or sand and gave a very smooth road, less noisy than the ordinary one on wooden sleepers. It was above all remarked that the ballast got perfectly

Digitized by Google

moulded to the interior shape of the sleeper, so as to form part of the sleeper, and that the solidity of the track got so much the more augmented. But it was soon found that the fastenings were defective. The bolts, which seemed to hold well at first, became unscrewed, and it was never after possible to tighten them up in a satisfactory way in spite of all the efforts made. Nevertheless on a line so little worked as that between Besançon and Bourg, which only had four or five trains a day, and at low speed, these sleepers were able to remain eight years in track. Apart from the frequent tightening up they exacted no more attention than those of wood; but the renewal of a single sleeper was always more difficult. In such case it was necessary to draw the bolts of the two neighbouring sleepers and force the rail with the crowbar to free the latter from the saddle. In 1872 many of these sleepers were in a bad state. The holes pierced in the saddle and the sleeper enlarged, the cotters were no longer kept fast without the addition of wedges which themselves held with difficulty. For these reasons all these sleepers were taken out and sold as scrap.

Mr. Garet.

The cross sleepers of the type PLM,A (Fig. 48, section at joint, Fig. 49, intermediate section), were laid on the line from

FIG. 48.

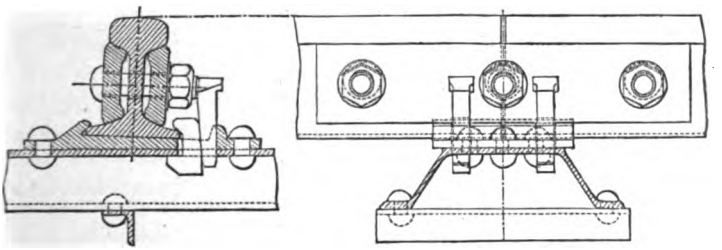
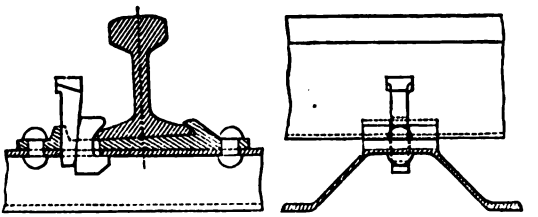


FIG. 49.



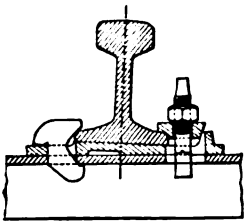
Paris to Dijon, and revealed, very shortly after laying, defects even more serious than the loosening of the fastenings. They split at the upper angles of the V irons to the right of the rivets holding the saddle, and the joint-sleepers, which had angle-irons riveted to

Digitized by Google

Mr. Garet. the underside, broke right across at this place. Sleepers of type PLM,A being removed, they were replaced by those of type B, which, not having resisted better than the first, remain with them experiments only. The fastenings held much less than in the Besançon and Bourg line, on account of the number and speed of the trains. After less than two years and a half the road got so shattered between Malain and Velars that it was necessary to remove all the sleepers.

Towards this time the wedge and cotter were experimentally replaced in a certain number of sleepers by a clip-and-bolt fastening, as in Fig. 50. Fifty sleepers were so provided on the length between Maison Alfort and Villeneuve St. Georges. This fastening gave much better results, but the breakages did not cease; the holes of the bolts and cotters continued to enlarge, and it became dangerous to let the sleepers remain longer in service, when the substitution of steel for iron rails opportunely put an end to the experiment in the early part of 1870.

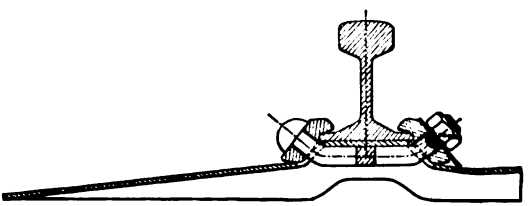
FIG. 50.



A length of 3,000 metres of type PLM,B, laid on the Grasse branch, was furnished partly with clip and cotter fastenings and partly with bolts and washers. In the first case a great many broken cotters were found, in the second virtually none. It was attributed to excess of grip, which was more readily occasioned with wedges driven by blows of a hammer than with the screwing up of bolts. It was necessary to renew a large number of fittings; so, under the fear of absolute failure, the sleepers PLM,B were removed towards the end of 1872.

The simplicity and at the same time the solidity of the fastenings in the Brunon sleeper (Fig. 51) led to some further experiments on

FIG. 51.



a small scale. In this case defects were no longer manifested in the fastenings, but there were other faults. The three hundred and twenty-eight iron sleepers had nearly all disappeared in February,

Digitized by Google

1878, on account of cross-fractures outside the rail seat. The one hundred and seventy-two steel sleepers were distributed as follows: forty-eight on the main line and one hundred and twenty-four on a siding having very heavy traffic at the Rive de Gier station. Of the former, eight were broken in September, 1878, and of the latter scarcely one remained in good condition. Mr. Garet.

As regarded the sixteen sleepers laid near Paris, they had resisted well so far; but it must be mentioned that these sixteen sleepers were very carefully attended to during manufacture, in a way altogether special; eight had been annealed, and eight were besides tempered in oil.

On the whole these trials of iron sleepers did not give sufficiently good results to encourage further experiment. At the present time, moreover, they were of comparatively little interest, seeing the low price at which wooden sleepers could still be obtained. The employment of iron sleepers, in his opinion, was attended also with one very serious drawback: in case of derailment, every sleeper touched by a wheel was at once broken; and in that way hundreds might be broken in succession. From this resulted the almost impossibility of making the track good unless by holding a large surplus of stores. Since the 23rd of December, 1878, when the above information was compiled, no further experiment had been made; but the sixteen steel sleepers, tempered or annealed, had remained in the road, near Paris, until the 12th of November, 1881, under very heavy traffic, and continued to hold out well. It was alleged, however, that they tended to pulverize the ballast (gravel and sand), to form mud quicker, and to require more frequent packing.

Mr. W. Hohenegger was of opinion that the Author's imitation of the Vautherin sleeper could give no useful result; in it the tendency of this section of sleeper to generate longitudinal cracks was even increased by the form of clip-fastenings. This clip necessitated a large hole in the weakest part of the sleeper, and this greatly diminished its strength. Further, the fastening by a wooden key was inadmissible in a dry climate like that of Austria. Mr. Hohenegger.

Mr. W. Jacomb stated that his experience of permanent way led to the conclusion that the simplest was the best and most economical. On the South-Western Railway one uniform arrangement had been adopted. Mr. Jacomb.

The rails were of steel, double-headed, weighing 82 lbs. per lineal yard. The chairs had a width at the base of 6¼ inches; their weight was 40 lbs. each, and they were attached to rectangular creosoted sleepers with three combined fastenings of spikes and

Digitized by Google

Mr. Jacomb. compressed hollow oaken trenails. The keys, 6 inches in length of compressed oak, were secured in the chair by a simple contrivance, a cut nail being driven into a vertical slot which was cast in the jaw of the chair. The rails were turned a good while before they got chair-worn.

Mr. Ledru. Mr. C. LEDRU, Chief Mechanical Engineer of the Eastern Railway of France, submitted the annexed report of Mr. Guillaume, presented to that company in May, 1877, on the results of experiments with metallic permanent way of various systems. The negative results so obtained accorded perfectly with the experience of the Belgian State Railway Company recently made public, which was that for lines of heavy traffic, or with heavy gradients and sharp curves, tracks with iron sleepers on the Hilf system were difficult to maintain, and much more costly than the ordinary wooden sleeper system. For the present the Eastern Company had abandoned all idea of further experiment in the same direction.

In this report it was stated that the trials of iron cross sleepers went back as far as 1865, when ninety-nine sleepers from the Fraisans Works and forty-eight from the Hayange Forge were laid in track II., kilometre 23, of the Mülhausen line. Forty-eight of the Hayange sleepers were laid at the same time in track I. between kilometres 6 and 7 of the Strasburg line. Finally, two thousand and ninety-eight additional sleepers of the Hayange type were laid in 1868 between kilometres 19 and 21, track II. of the Strasburg line. The Fraisans sleepers were of two types, and comprised—

FIG. 52.

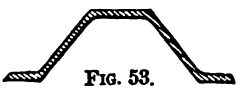


FIG. 53.

FIG. 54.

1. Fifteen joint, and forty-four intermediate sleepers of trapezoidal section (Fig. 52).

2. Forty intermediate sleepers of half-round (Zorès) section (Fig. 53); these were laid with joint-sleepers of oak.

The sleepers of the latter type all broke under the rails; their average life did not exceed six years and two months. The trapezoidal sleepers resisted better; nevertheless at the end of 1873, eight years after laying, out of fifty-nine, thirty-seven had been replaced, ten of which had split longitudinally. In consequence of the results, the trial of these types was not continued. The Hayange sleepers (Fig. 54), were laid as intermediates between joint-sleepers of oak, with the exception of two short lengths of 120 metres, laid, one with iron joint-sleepers, and the other with

Digitized by Google

suspended fish-joints. At these two places the joint-sleepers, or those nearest a joint, were notched to receive small wedges destined to prevent the longitudinal creep of the rails. Mr. Ledru.

All these Hayange sleepers had perfectly served to the present time, *i.e.*, twelve and nine years respectively, with the exception of those furnished with stop wedges and employed as joint-sleepers; seventeen out of twenty of these were taken out after eight years' wear, broken at the wedge notch. But they needed great attention. Since the second half of 1874, namely in 1877, for two and a half years, exact record had been kept of the state of the Strasburg line, and it had thus been possible to compare track II., furnished with iron cross sleepers, with track I., having wooden sleepers. The following was the total cost of labour for maintenance (not including the cost of new rails), taking the cost of wooden sleepers in track I. as unity.

1st trial (1865), 48 metres of track on intermediate sleepers of iron and wooden joint-sleepers between kilometres 6·600 and 6·648, track I.	1·53
2nd trial (1868), 120 metres of track on iron sleepers, joint and intermediate between kilometres 19·002 and 19·122, track II.	1·68
3rd trial (1868), 120 metres of track on iron sleepers with suspended fished joints, between kilometres 19·122 and 19·242, track II.	1·82
4th trial (1868), 1,758 metres of track on iron intermediate sleepers with wooden joint sleepers, between kilometres 19·242 and 21·000, track II.	1·53

The last trial was the most conclusive, owing to the greater length. The annual averages for labour reached, per kilometre—

	Days.
For intermediate sleepers of iron with joint-sleepers of wood	255·98
For wooden sleepers	167·34
Difference in favour of wooden sleepers, per kilometre per annum	88·64

or, taking the price for the working day at 3 francs 50 centimes, a difference of 310 francs 24 centimes per kilometre.

The iron sleepers lacked stability; they required frequent packing; after heavy rains the water got inside the sleeper and dislodged the ballast, which thus failed to provide a permanent support against the sleeper. Nevertheless the trials were made under favourable conditions for the formation of such support, and it was probable that with broken stone ballast the gap in the sleeper would be still more difficult to fill up.

Digitized by Google

Mr. Ledru. Much attention had been devoted to the mode of fastening the rail to the sleeper. It was inferred that the sole difficulty lay here, and that success depended upon this alone. The trials on the Northern, the Paris and Lyons, and the Eastern railways, showed that this difficulty was not important; in particular the clip and cotter fastening of the Fraisans sleeper gave good results. The Hayange fastening, consisting of a frog kept tight by a bolt, was less successful; at first the nuts got unscrewed, and the frogs were displaced by the vibration; but tightening the nuts only demanded trifling attention, and afterwards the working loose was stopped by notching the thread of the bolt.

In 1862 Mr. Barroux, chief engineer, laid on the Bar-sur-Seine line, near Troys, 120 metres of Vignoles rails on longitudinal sleepers of flat iron, 9·8 inches broad and 0·39 inch thick, connected at every 10 feet (3 metres) by angle-iron ties, furnished at mid-length with wingpieces forming stops (arrêts de ripage). This track, laid on excellent ballast and on a solid subsoil, and having to support only a small traffic at low speed, answered fairly well, but cost notably more for maintenance than the cross-sleeper road. The joints of the rails were especially difficult to keep in order, although they broke joint with those of the sleepers, which latter offered but slight resistance to bending. Also this line becoming part of the principal line to Mülhausen, Mr. Barroux judged that it would be difficult to maintain the longitudinal sleepers, and authorised their replacement by the ordinary track.

Hartwich's system, so enticing at first view by reason of its simplicity and low price, was the subject of a trial followed with close attention from April 1869. A length of 1,200 metres of single track was laid on the Mülhausen line between kilometres 312·900 and 314·000, of which 420 metres were in a cutting, the road bed of which was clayey, wet, and of little consistence, and 780 metres on embankment formed of excavation from the cutting. The ballast was broken stone mixed with earth and clay. There was a gradient of 1 in 166 for 890 metres, and a curve of 3,280-feet radius for 310 metres. Ten trains passed daily. This track always showed great instability.

In the cutting, the pressure on the rails formed ruts in the road-bed, which changed from side to side. Numerous lateral deformations arose in spite of the precautions taken never to lay bare the middle of the track. It was endeavoured to remedy this by draining the road-bed, covering it with a mattress, and renewing the ballast. Further, some of the round rods not being strong enough to maintain the cant of the rail, were replaced by

Digitized by Google

rigid ties, and sole-plates were laid under the joints to remedy the subsidence which there was more pronounced. Mr. Ledru.

But notwithstanding the improvement thus produced, the Hartwich track always necessitated much more labour than the P. M. fished track between which it was introduced, and which was subject to the same conditions. At the end of the first half of 1876, for a period of one hundred and six months (allowing for the six months' interruption caused by the war), the average monthly cost for labour of the Hartwich track was 186 fr. 41 c., and of the P. M. fished track 92 fr. 7 c. In presence of these figures it need only be said that the Hartwich track must be definitively rejected; this was indeed the result arrived at in Germany.

The Hilf track had not been tried on the Eastern of France Railway; but the results of Messrs. Petsche and Bruniquel's trials in Alsace and Lorraine might be summed up in the following extracts from the report of Mr. Bruniquel, dated the 14th of November, 1876:—

"Although the opinions of the German engineers are generally favourable to the new (Hilf) system, the following faults are alleged against it:—

"1. The sleepers, even on slight gradients, get displaced longitudinally.

"2. The rails slide on the sleepers.

"Finally, as the sleeper is only buried 2½ inches, it is feared that frost and thaw have great influence on the track, and one is led to think that to obviate this recourse must be had to broken stone ballast."

* * * * * *

"It has not been possible to obtain exact information as to the cost of maintenance of the Hilf track. Indeed, its application in Alsace-Lorraine is too recent for the repairs to the present time affording a fair criterion of the average cost of maintenance. All that can be said is that labour does not appear to have been spared."

Mr. Petsche, among other comments added to the report of Mr. Bruniquel, said:—

"The laying of the permanent way is far from being done with all the care necessary. I have seen tracks laid only a few months which showed rises and sinuosities never noticed on our lines when arrived at their normal condition."

The foregoing showed clearly that the Hilf system lacked stability. Laid, so to speak, on the surface of the ballast, it was exposed to all the atmospheric influences. The gauge of the rails

Digitized by Google

Mr. Ledru. was only maintained by feeble ties of rod-iron, which did not resist the slightest derailment, and which were otherwise powerless to preserve the proper cant of the rails, so necessary for the steadiness of the rolling stock.

The cost of the Hilf track was very high. The weight of the longitudinals, ties, fastenings, &c., reached 134 lbs. per yard. It was true that the weight of the rails was reduced to 58 lbs. per yard; but these rails, of steel, had weak heads, which would not stand, as did 66-lb. rails, a wear of $\frac{1}{3}$ to $\frac{1}{2}$ inch. The sum of which was that the Hilf system, of which the German engineers were so enamoured, would have a similar fate to that of Hartwich, heralded at first with an enthusiasm quite as general, and at present completely abandoned.

Mr. Mangini. Mr. MANGINI, Engineer of the Dombes and South-Eastern Railway of France, had used for the last twelve years on that line blocks of hard close-grained limestone for supporting the rails, and with excellent results. Various modes were employed: one consisted in placing ordinary sleepers under the joints of the rails, blocks forming the intermediate supports; another alternated a stone block with a sleeper. All these systems gave satisfaction; but experience was in favour of the combination indicated by S S B S B S B S S (two sleepers for the rail-joint, then a block and sleeper alternately to the next joint). This necessitated six hundred and twenty-five sleepers and seven hundred and fifty blocks per kilometre of single line (one thousand and twelve hundred and fifty per mile respectively). The rails were steel of Vignoles section, 8 metres (26¼ feet) long, and weighed 60 lbs. per yard. The dimensions of the blocks were 50 centimetres by 50 centimetres and 25 centimetres deep (say, 20 inches by 20 inches by 10 inches). The rails were spiked to oak plugs inserted in holes 1½ inch in diameter sunk in the block. It was necessary to use dog-spikes instead of wooden-screws, the plugs being cut the way of the fibre. The surface of the block on which the rail rested must be perfectly dressed; as in the case of sleepers it was slightly recessed. The proper cant for the rail was given by tilting the block. The cost price was 1f. 50c. to 2f. 10c. per block drilled and plugged. It had been especially noticed that this road opposed more resistance to lateral displacement, owing either to the weight of the blocks or to their large surface. For instance, ordinary steel rails of 60 to 70 lbs. per yard gave stability at least equal to the 80-lb. rails on cross sleepers used for a length of 12 kilometres elsewhere. The limestone being excellent the blocks were in no way deteriorated by a

Digitized by Google

service of twelve years. Similar blocks made of concrete had been found equally serviceable, but their employment was superfluous, the limestone being cheap and abundant. He now used that sort of permanent way only, and was about to lay it on the line from La Cluse-Nantua to Bellegarde. Mr. Mangini.

Mr. T. E. M. MARSH observed that the subject had received much of his attention, extending back to the earliest attempts to substitute iron for timber, and when he had the special charge of such matters for the late Mr. I. K. Brunel. The combinations of cast iron should not, however, be excluded, as unquestionably ordinary rails and fastenings on cast bowl sleepers, or forms known as Livesey's, or De Bergue's and others, were deserving of consideration; for in some cases they superseded the use of wood with marked economy. The efficiency of the fastenings and strength generally of most of the Continental permanent ways referred to by the Author, would, he thought, hardly prove satisfactory on most of the heavily worked high-speed English lines, though they compared advantageously with their own previous construction with dog-nail spike and fastenings on fir sleepers. The iron or steel cross sleeper and fastening, such as the specimen prepared by Mr. Webb, was, he thought, most satisfactory, and it would be desirable to have the results of the trials on the London and North-Western Railway or other first-class lines; and especially to know at what cost the complete sleeper with affixed chair could be purchased in the open market, to contrast it with the best wooden sleepers, with its chairs and fastenings, which had gradually come to be so large a portion of the first cost. The iron sleeper appeared to give good prospect of its advantageous introduction, if the cost came so close to the wooden one with its fastenings. The jaws might of course be varied in form to suit any rail; and he thought possibly some improvement might be made in the three plate surfaces and the riveting connection. The Barlow rail permanent way had been extensively used by the late Mr. Brunel, as the simplest and cheapest form of permanent way, having the required strength for the heavy rolling loads. The faults were chiefly due to the defects at the joints after some wear. There was also another difficulty in the way of continuing the use of these rails on main lines, arising out of the fact that manufacturers did not care to roll them when wanted; and the form of pile used and mode of rolling was unfavourable to the production of good rails such as Mr. Brunel generally obtained. These rails, however, did good service now in sidings, and would long survive, costing little for maintenance. They were also Mr. Marsh.

Digitized by Google

Mr. Marsh eagerly sought after for bridge decking and platforms, when useless as rails. Now that such sections could be produced of steel as readily as the longitudinal and cross-sleeper forms of bearers, he thought they might be so improved as to render good service for some cases, such as opening up poor countries and colonies where the first cost of other rails capable of carrying heavy loads could not be entertained, and when also simplicity and transport of material were desiderata. He might be considered rash in the notion of resuscitating this form of permanent way, but in steel there was much to recommend it for such cases.

Mr. Mathieu. Mr. HENRI MATHIEU, though not quite conversant with what was being done in France relative to metallic sleepers, believed himself justified in saying that their use had hitherto been confined to some short experimental lengths. It was principally urged against them that they provided insufficient attachment to the rail, which was doubtless owing to the small thickness of the material employed.

On the Southern of France Railway, with which he was connected as Engineer-in-Chief, they had never even been tried, and the company had no interest in the question. The Landes, which that line traversed, and also the Pyrenees provided all the pine and oak necessary, and at a price so low that iron sleepers would never be able to compete with them. Thus pine sleepers unprepared cost 1*s.* 7*d.* to 1*s.* 8*d.* each delivered on the line, and when impregnated with sulphate of copper or with creosote, 2*s.* 2*d.* and 2*s.* 4*d.* respectively. When in England in 1875, he had been much struck with the stability of the track, which he attributed to its weight. This varied from 230 to 250 kilograms per lineal metre (463 to 504 lbs. per yard), while in France, the greatest weight then attained, did not exceed 200 kilograms per metre. This impressed the manager of the Southern Company, who did not hesitate to follow the example of the English engineers, and at present the track consisted of steel rails 11 metres (36 feet) long, weighing 76 lbs. per lineal metre, of 33-lb. chairs, and sleepers 8·8 feet long by 13 inches wide and 11 inches deep, and weighing (when of creosoted pine) 166 to 220 lbs. each. The weight of such a track was thus about 436 lbs. per lineal yard, and that was not too great. If, instead of wooden sleepers, costing at the outside 2*s.* 4*d.* each, iron sleepers were used, the same price would only purchase sleepers weighing from 24 to 26 lbs. (11 or 12 kilograms), while the wooden sleeper attained 220 lbs. In presence of such inferiority it would be imagined that as long as the Landes and the Pyrenees were covered with forests, the

Digitized by Google

type of permanent way adopted on the Southern of France Railway would not be altered. Finally, the wooden sleepers were less noisy than tracks entirely of iron. Mr. Mathieu.

Mr. ROUGIER, Engineer-in-Chief of the Paris and Orleans Railway, remarked that the French companies had not hitherto concerned themselves much with metallic sleepers, because, apart from engineering considerations, in the French market the price was at present much in favour of wood (his company paid from 3*s.* 9*d.* to 4*s.* 2*d.* each sleeper). He only knew of the experiments made by the Lyons Company, first with sleepers of *zorès* iron, and later with Brunon's steel sleepers. The results obtained seemed to indicate but moderate success, and the experiments had not led to the introduction of metallic sleepers for general service. He did not think it possible to obtain the same stability, elasticity, and easy running, from iron sleepers as from those of wood. The experience of the German companies from an extended use of the Vautherin sleeper seemed to put this past dispute. They showed besides that the complication, and the unstable nature of the connection between rail and sleeper, led to excessive cost of maintenance, besides importing risk to security of running. Mr. Rougier.

Mr. C. P. SANDBERG observed that he was familiar with the systems of iron permanent way laid in Germany. He was inclined to regard the iron permanent way as an evil, which would have to be adopted in the course of time. It wanted elasticity, which would increase the liability to fracture of the rolling stock, and the rails, and the danger of accidents, particularly where the speed was high and climate cold. In the systems hitherto used there was much difficulty in maintaining the gauge, and in fixing the rail to the sleeper. And it was unpleasant travelling for passengers, from the rigidity and noise of the iron roads as compared with rails on wooden sleepers. He thought iron sleepers would supersede wooden ones, owing to the necessity of sparing the forests, for wood was becoming every day dearer, and iron cheaper. With the increased mileage of railways a period might come, under the present system, when all the forests would be consumed. It was well known, too, that as forests were destroyed, the climate was deteriorated, and many countries might in this way become uninhabited. There was much truth in the popular saying in Sweden during a cold winter that "The forest is the poor man's coat." Hence the necessity of not using wood when iron would serve as well. Mr. Sandberg.

The present high speed would certainly retard the introduction of iron permanent way on railways in England. Steel, and especially iron, was apt to lose its elasticity in the course of time when

Digitized by Google

Mr. Sandberg. subjected to incessant strain. There had not been sufficient experience, however, to prove this. It did not exclude the adoption of iron permanent way on lines where the traffic was light and the speed low. It only meant that precaution should be taken, not to introduce it first on main lines, but on branch railways. This had been done on the Continent. On the main line of the Cologne and Minden Railway, where fast expresses were run, the iron permanent way had been much more slowly adopted than on the Rheinische and the Bergisch-Märkisch Railways, where the speed was not so great. Climate had a marked influence on the success or otherwise of iron permanent way. In hot climates the corrosion of wrought iron and steel was great as compared with cast-iron or pot sleepers. Nevertheless, the high cost of wooden sleepers in those countries often rendered the adoption of some sort of iron sleeper essential. A temperate climate was the best, such as that of England and central Europe; for corrosion was not so rapid as in the South, nor was the ground so long frozen as in the North, and this was certainly one of the reasons why German engineers had been comparatively early in the field in introducing iron permanent way.

Happily in countries with cold climate, such as Canada, Russia, and Scandinavia, forests were comparatively plentiful, and hence the economical advantage was seldom so great as to tempt engineers to substitute iron for wood. The last calculation made by the Swedish Government State Railway Department as to the comparative value of iron and wooden sleepers for their roads showed, that even if wooden sleepers should become twice as dear as at present, 1*s.* each, they would still be more economical; and for safety of traffic they were almost invaluable.

The nature of the soil, the road-bed and ballast affected iron more than wooden sleepers. So far as he knew ordinary ballast or sand had nowhere given satisfaction when used with the former; coarse ballast of stone or slag was absolutely necessary for iron sleepers. Another matter of great importance was the solidity of the road-bed. Hitherto iron sleepers had only been used on old roads where the bed had been already set, during many years of traffic on ordinary sleepers. Sufficient experience had not yet been gained of the behaviour of iron sleepers on newly-constructed ordinary roads; therefore in calculating the comparative cost of sleepers the extra cost of stone ballast should be taken into account. Another difficulty in using iron sleepers in cold climates would follow from the sudden change of level of the sleepers through the freezing of the water when the drainage was imperfect. This,

Digitized by Google

sometimes in a few hours, would alter the level of the line 6 or 7 inches, where water poured up in the ballast under the sleeper, and would obviously be much more difficult to remedy than with wooden sleepers. Mr. Sandberg.

Mr. H. SCHEFFLER observed that a scheme for a system of iron permanent way, described in the "Organ für die Fortschritte des Eisenbahnwesens" in 1862, had been carried out on two portions of the busiest part of the Brunswick Railway, each 0·45 mile long, in September, 1864. The construction of the permanent way on these two lengths was shown in Figs. 55 and 56. Different designs were used on each to ascertain the best position for the transverse connections, and the minimum dimensions admissible for the Mr. Scheffler.

FIG. 55.

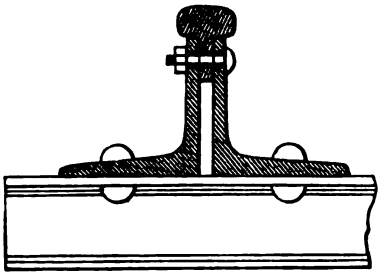
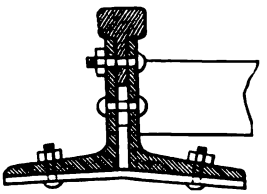


FIG. 56.



sleepers. Sleepers and transverse ties were connected by rivets, the rails were fastened to the sleepers by bolts at intervals of 1·4 foot. The joints of the rails and sleepers overlapped each other, and those of the latter were strengthened by wrought-iron fish-plates screwed on underneath. The bolt-holes in the latter and in the rails were oval, to allow of any elongation due to differences of temperature. Both portions of line lay side by side, and were straight; one half of each was laid on good and porous, the other in poor, fine, and impervious gravel; they had been in use for sixteen years, and were traversed daily by from twenty-five to forty trains of all kinds, including very heavy goods and coal trains. The condition of both lengths of permanent way had been, on the whole, satisfactory, less repairs being necessary than for other parts of the line. With the design, Fig. 56, some cases of depression and deflection had occurred on the breaking up of a severe frost in 1865, which were subsequently traced to defective ballast and foundations.

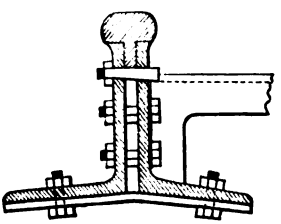
The great depth of the sleepers might be principally credited with the good results obtained, as it rendered a low position of the

Digitized by Google

Mr. Scheffler. base of the sleeper possible, and protected it from the action of frost. The permanent way was easily raised and packed. Apprehensions, widely expressed, that the smooth under-surface of the sleepers would lead to lateral displacement, had proved groundless; in every case where this had taken place it was due to the ballast having been washed away.

Up to the end of the year 1880 the number of sleepers replaced on account of fractures was: for Fig. 55, 25; for Fig. 56, 41. In latter years, here and there depressions in the upper surface of the sleepers had occurred under the rail joints in both constructions, and in Fig. 56 the rivets fastening the transverse ties had frequently worked loose; the first defect was met by altering the position of the rail joint, the latter by hammering cold. As with ordinary fish-plates, the bolts securing the rails required in places frequent tightening up. With the design, Fig. 56, a tendency of the rails had latterly appeared to move forward in the direction in which the trains ran. This was probably due to the fact that the ballast between the rails could only be brought up to the lower edge of the transverse ties, otherwise these, owing to their light character, might easily have been bent by the thrust. The form of transverse connection shown in Fig. 57 met this evil. In the sixteen years ending 1880, all the iron rails had been replaced; but as they were subjected to the heaviest traffic on the Brunswick Railway, this was not remarkable. The oxidation of the iron permanent way had been insignificant. Neither construction appeared to possess any marked advantage over the other; trains ran rather harder over the iron sleepers than over wooden ones, but more uniformly and quietly. It was found difficult to roll the vertical flanges of the sleepers in systems, Figs. 55 and 56, with the upper edges, on which the rails rested sufficiently accurate, and hence it became necessary to partially plane them. To avoid this, a third system of permanent way, represented in Fig. 57, had been laid, to the extent of 0·93 mile, partly on a curve, on the line between Brunswick and Wolfenbüttel; it had been in use since the beginning of 1867 to the extent of 0·8 mile.

Fig. 57.



In this system cotter-bolts were used to attach the rail to the sleeper. The rails were of cast-steel, the transverse ties of ⌐¬ section, and 5 feet apart. The Bessemer steel used for the rails was so brittle that some of the latter were broken by falls

Digitized by Google

during unloading; and after being laid, four hundred and twenty-three out of five hundred and twenty had to be replaced by puddled steel rails, in consequence of fractures, up to the end of 1880. The fractures always occurred where the rails were punched. In latter years fractures had taken place in some of the sleepers, and here and there, as in systems Figs. 55 and 56, the ends of the rails had been driven into the upper surface of the sleepers, although not to the same extent as in the former structures. The system shown in Fig. 57 possessed the advantage over ordinary wooden sleepers, that broken rails might be retained; but to avoid breakages altogether, a fourth system, Fig. 58, had been adopted. This system was laid on the line between Kreiensen and Holzminden, for a length of 11¼ miles, the maximum gradient being 1 in 80, and the sharpest curves of 1,197 feet radius. One portion of this line had been at work for twelve and a half, the other for twelve years. The rails were principally of cast steel. The pressure resulting from the tendency of the rails to creep forward, was in this system sustained by a single bolt at the end of each rail, and, consequently, the former had been indented by the latter, and in some cases abrasion of both parts had occurred; besides this, depressions in the sleepers occurred under the rail joints, and on sharp curves the ends of the rails were crushed. These depressions were generally the result of defective welding or of fractured sleepers; the fractures, which here and there took place, were always at the points where the sleepers were punched for the cotter-bolts. The wear of the steel rails had hitherto been insignificant on this section of the railway, except where the brake was regularly applied. The use of cotter-bolts had been, on the whole, successful. In 1879 and 1880, when the line was undergoing repairs, the iron bolts were replaced by steel ones. The good results obtained with systems, Figs. 55 and 56, led to the adoption of another design, Fig. 59; this modification was intended to obviate the difficulty presented by system, Fig. 58, to the formation of switches, and to bring down the cost of the iron permanent way as nearly as possible to that of ordinary wooden sleepers. It differed from Fig. 57 in having reduced

Mr. Scheffler.

Fig. 58.

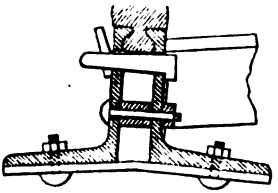
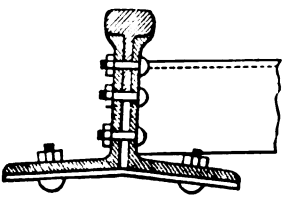


Fig. 59.

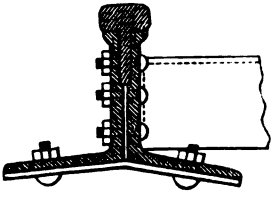


Digitized by Google

Mr Scheffler. dimensions for the angle-irons, in being furnished with transverse ties of angle-iron instead of ⌐¬-iron, and in the connections being made with common bolts instead of cotter-bolts. This system had been laid on the line between Seesen and Osterode for a length of 9 miles, and having gradients up to 1 in 180, and curves of 1,493 feet radius, the rails being of fine-grained iron. The results obtained with system, Fig. 59, were not so favourable as was expected; the material of which it was made being, however, defective, it was impossible to decide whether the large number of depressions on the sleepers during the ten years the permanent way had been in use were due exclusively to the latter cause, or partly to the reduced dimensions, or the freshness of the earth-works and ballasting. To prevent the depressions in the sleepers above referred to, the experiment was made, in 1877, of laying separate plates under each rail-joint. In the annexed Table the cost of these plates had been included.

Fig. 60 was a modification of the construction of Fig. 59, in which the vertical flanges of the sleepers were increased in thickness, and so arranged that the rail received a double support. These sleepers had been in use on a length of 984 feet since 1877. Hitherto this design had given good results, and during the three years it had been at work not the slightest depression had taken place under any of the rail-joints. The following were the weights and prices, delivered where required, exclusive of the cost of laying and ballasting:—

Fig. 60.



System Fig.	55 = 120	lbs.	= 35·9	marks.
„ „	56 = 109	„	= 30·1	„
„ „	57 = 102	„	= 30·3	„
„ „	58 = 96	„	= 28·6	„
„ „	59 = 84	„	= 24·9	„
„ „	60 = 92	„	= 27·6	„

As compared with this, the ordinary system of permanent way, with rails 5·4 inches high of cast steel, costs 22·3 marks, and with rails 4·8 inches high, 18 marks. The iron permanent way, when once the workmen were accustomed to it, could be put together and laid quickly and easily.

The depth of the ballast bed under the sleepers was the same as for wooden sleepers, *i.e.*, 11·2 inches; this had been found sufficient, but it was of great importance that a clean porous ballast should

Digitized by Google

be used, and efficient arrangements for drainage made, also that the iron permanent way should be entirely bedded in good gravel, which ensured easy travelling. The cost of maintenance in different years had varied from 0·37 to 0·8 mark per lineal metre. None of the apprehensions entertained by many engineers as to the want of success of iron permanent way had been justified. The following was a statement for each of the systems of permanent way, Figs. 55, 56, 57, 58, and 59, of the average proportion of rails replaced per annum, expressed as percentage of the total length of line laid on the system in question:— Mr. Scheffler

System.	Number of Years.	Average Percentage.
Fig. 55	16	6·791
„ 56	16	7·110
„ 57	14	5·758
„ 58	12	2·833
„ 59	10	4·860

No rails of system, Fig. 60, had as yet been replaced.

The use of rivets in the construction of those portions of the iron permanent way which did not need frequent renewal, more particularly those which were covered by the ballast, was by no means objectionable. Cotter-bolts had not proved more effective than ordinary bolts. The fears entertained as to the lateral displacement of the permanent way had proved groundless, except where the ballast was defective. Changes of temperature had produced no bad effects as regarded longitudinal expansions. Experience had shown that on railways with considerable traffic, a width of 11·6 inches was necessary for the sleepers.

The design, Fig. 60, might be regarded as the final embodiment of the experience gained by the trials described. With every system the drawback had been found, that the ballast-bed under the sleepers was always becoming more compact and impervious from the continued accumulation of dirt; on the other hand, this had the advantage of giving increased resistance to lateral displacement, and affording greater protection against frost.

Of late years the experiment had been made of placing drain-pipes transversely under the longitudinal sleepers, to facilitate the drainage of the ballast, and as far as could be ascertained hitherto with success.

Notwithstanding sixteen years' experience, the Directors of the Brunswick Railway did not consider the trials as concluded; but in spite of the reduced price of iron, permanent way with wooden cross sleepers was still cheaper than any of the iron systems. It should be mentioned that on the line between Stadtoldendorf and

Digitized by Google

Mr. Scheffler. Holzminden with a descending gradient, as well as on that between Brunswick and Wolfenbüttel, the iron permanent way had sustained admirably the running off the line of several wagons, the result being only a slight deflection of the transverse ties, and the destruction of some of the connections, but without displacement or change in the gauge.

The oaken sleepers used on the Brunswick railways had the following dimensions: Length, 8 feet 2½ inches; width, 11 inches; and thickness, 5·5 inches, giving a bearing surface of 7·53 square feet, and side area for resisting longitudinal displacement of the permanent way of 3·77 square feet, a cubic capacity of 0·13 cubic yard, and when damp, a weight of 198 to 220 lbs. The price of a sleeper, including impregnation, planing and carriage, was in 1878, 5·86 marks, and this varied little from year to year. The average duration of sleepers impregnated with chloride of zinc was about twenty years. Old sleepers might be valued at 0·5 mark each as fuel. The transverse iron sleeper proposed by the "Horster Union," which corresponded in dimensions with that used on the Bergisch-Märkisch Railway, had a length of 7·2 feet, width of 0·75 foot at the bottom and 3 inches at the top, and a height of 2·6 inches. It was made of iron plate 0·3 to 0·5 inch thick, and was open at both ends; the bearing surface was 5·38 square feet, the side area 1·51 square foot; the cubic capacity buried in the ballast was 0·78 cubic foot, and the weight 103·5 lbs. Sleepers with open ends having proved defective on other lines, the Bergisch-Märkisch Railway Company used sleepers in which the lower ends of the flanges were connected by two angle-irons, which increased the above-mentioned weight to 115 lbs.; on other railways it was found necessary to use four transverse ribs. The sleepers, without transverse connections, cost 5·84 marks each; those with two angle-irons 7·12 marks, and those with four connections 7·8 marks, delivered at a station near the ironworks; for the Brunswick Railway the cost of carriage would bring these prices up to 6·36, 7·7, and 8·4 marks respectively.

The deflection of iron sleepers of this pattern under a given load was greater than that of the oak sleepers previously described; with the points of support 7·2 feet apart, the deflection was—

For an oak sleeper	with	3,085 lbs.,	inappreciable.	
„ „	„	5,511 „	0·157	inch.
„ iron	„	3,085 „	0·394	„
„ „	„	5,511 „	0·945	„

and with the latter load the iron sleeper sustained a permanent deflection of 0·413 inch.

Digitized by Google

Mr. Scheffler.

The iron sleepers in question did not comply with the regulations for the Prussian State railways, and if the necessary modifications were made, the prices would be increased for the three types of construction referred to, to 7·33, 8·67, and 9·37 marks respectively.

The value of any system of sleepers depended on the bearing surface necessary to carry the traffic.

The square-metre bearing surface (10·76 square feet) cost, for wooden sleepers, 8·37 marks; for iron sleepers of the kind in question, 16·2 marks. The wooden sleepers were buried deeper under the surface than the iron ones; were consequently less exposed to the action of water and frost, and, on account of their form, they offered greater facilities for packing up with ballast.

The wooden sleeper opposed an area of resistance to longitudinal displacement of 3·77 square feet; the iron one 1·61 square foot; against lateral displacement the areas presented were respectively 0·43 and 0·22 square foot. On account of the greater friction of iron sleepers, where gravel must slide on gravel, the resistance to displacement was probably not less for the latter than for wooden sleepers. The unsupported length of rails with wooden sleepers was 2·13 feet; with iron ones, 2·49 feet. Iron transverse sleepers required, for every different radius of curve, different methods of attachment, or holes differently punched. The conclusion arrived at was that no pecuniary advantage could be derived from the use of iron transverse sleepers instead of wooden sleepers of the same carrying capacity, as the first cost was at least twice as great for the former, and it was uncertain whether this could be neutralised by greater durability.

In England, where iron was cheap and wood dear, and where the heaviest traffic prevailed, perhaps the best field for a trial of iron sleepers was presented, but in Germany the conditions were different.

The total length of iron permanent way laid on the Brunswick railways since 1864 has been 23½ miles, and, as already stated, the results had been satisfactory. Hitherto, however, every system of iron permanent way had, at average prices, proved dearer than permanent way with wooden sleepers. If it was assumed that the greater first cost of iron sleepers was compensated by their greater durability, the question as to relative value would depend on the wear and tear of the rails. The system of permanent way in three parts was the result of the reduction of size of rail to the admissible minimum. The construction in two pieces, and still less in one piece, did not admit of this reduction. The separation of the rail

Digitized by Google

Mr. Scheffler. from its support was an essential feature of any practical system of permanent way. It was only necessary, therefore, to compare the triple with the double system. A careful comparison led to the following conclusions:—

Systems of iron permanent way, with transverse as well as with longitudinal sleepers, might be of a firmer and more durable design than those constructed with wooden sleepers; the first cost would however be greater, and the cost of maintenance could scarcely be reduced to the extent of compensating for this—iron sleepers, on account of the thinness of the metal, not having much durability. The use of iron permanent way of sufficient proportions thus involved a pecuniary sacrifice in the interests of safety. At present, iron permanent way might be considered as in an experimental stage. In designing any new system, attention should be paid to the following particulars and conditions: The dimensions should not be reduced at the expense of efficiency; great attention should be paid to the quality of the material; forms should be used which did not involve excessive strains on the iron in rolling; constructions avoided which necessitated great strains on the connections, &c.; the transverse ties should be placed as deep as possible; sufficient strength of the attachment of the rail against longitudinal displacement provided; and, finally, efficient drainage and good ballast.

In conclusion he wished to correct a few errors in the Paper. Mr. Hartwich had not laid the first iron permanent way in Germany, as he had executed a project, in 1864, which he had contemplated in 1862. Then again, the statement: "But the rail is weak, and causes trouble by lifting and breaking. To meet the difficulty, Mr. Daelen introduced a modification in 1868," was probably based on an erroneous report. The road in question, A.B.C., was still in use after seventeen years' traffic, and fitted with the original rails laid in 1864. and 1867. The breaking of the steel permanent way was not due to the construction, but to the brittle character of the material, and had occurred on all lines, even those provided with Vignoles rails. Steel rails had, however, a great advantage over ordinary three-part iron rails, in that there was no danger even when they broke. Fracture, when it did occur, was generally in those parts where the rails were riveted, and so the construction Fig. 58 was used, in which no rivet-holes were necessary. This form had not been introduced by Mr. Daelen, but by himself, although the introduction was the result of a conference with Mr. Daelen, who was the manager of the rolling-mills and proposed the new form. But in this system the

Digitized by Google

rail could not be riveted to the chair, and had therefore a strong tendency to lift, for it was not kept sufficiently down by the rail with which it was connected at the end. Owing to this fact he had latterly returned to the original system of form Figs. 59 and 60. Mr. Scheffler.

Mr. J. W. SCHWEDLER, of Berlin, remarked that to form an opinion as to the suitability of the construction of any permanent way, experience alone was insufficient. The theoretical conditions to which the form of structure was subject must first be determined, and then the sufficiency of the hypothesis tested by observation of the actual phenomena. With this purpose he would first discuss the theory of the longitudinal sleeper permanent way. The two assumptions on which this theory was based were the following: Mr. Schwedler.

1. The ground under the longitudinal sleepers was compressed to an extent corresponding to the load rolling over it until almost complete elasticity was produced. After this the elastic compression of the ground was proportional to the load and inversely proportional to the continuous bearing-surface of the sleeper.

If the coefficient of elasticity of the ground was denoted by C, the width of the sleeper by B, the depression by y, then the reaction p per unit of length (centimetre) of the sleeper was

$$-p = C \cdot B \cdot y.$$

Now as rails and sleepers together formed a single system of girders, subject to the deflections y, when the pressure of the wheels P = 7,000 kg. (15,432 lbs.) acted upon it, and as for elastic beams, the equation $E I \frac{\delta^4 y}{d x^4} = p$ held good, where E was the coefficient of elasticity of the material composing the permanent way, and $I = I_1 + I_{11}$, the sum of the moments of inertia of the sectional areas of rail and sleeper, with reference to the respective centres of gravity of these areas; therefore the theoretical fundamental equation for this system was

$$E I \frac{d^4 y}{d x^2} = - C \cdot B \cdot y.$$

2. The resistance of the ground, increased in the first place with the compression, reached a limit at which yielding took place through displacement. This, for the unit of length of the sleeper, was proportional to B^2, as demonstrated in the sequel. Hence the equation

$$p = \sigma B^2,$$

where σ denoted the coefficient of resistance of the ground.

Experiments on the Alsace-Lorraine Railways had shown that, with

Digitized by Google

Mr. Schwedler. wet and soft ground, C was as low as 2 kilograms per square centimetre, and that with firm ground it reached 8 (113·52 lbs.) and more kilograms, but generally 3 kilograms (42·57 lbs.) might be taken. The coefficient σ had not yet been experimentally determined. Theoretically it would amount for sharp sand to about 0·08; with different kinds of longitudinal and transverse sleepers it was calculated at from 0·04 to 0·08 (0·567 to 1·135 for English measure). The larger this coefficient was assumed to be, the more must the permanent way sink to attain elastic resistance; hence it constituted the measure for the permanent level of the rails if the vertical load only was considered.

On the basis of these two hypotheses the mathematical development of the fundamental equation for the longitudinal sleeper permanent way gave, for the resistance of the latter to a vertical concentrated load, the two following relations between the dimensions and coefficients:—[1]

$$1.\ k = \frac{P e}{4 I} \sqrt[4]{\frac{4 E I}{C B}}.$$

$$2.\ \sigma = \frac{P}{2 B^2} \sqrt[4]{\frac{C B}{4 E I}}.$$

where k was the maximum stress per square centimetre in the flange of the rail, and e the height of the centre of gravity of the partially-worn rail above the base of the latter. If the factor $\sqrt[4]{\frac{C B}{4 E I}}$ was denoted by m, and by M_0 was understood the bending moment of the permanent way under the wheel, the above formulæ might be more conveniently written

$$M_0 = \frac{I k}{e} = \frac{P}{4 m};\ p_0 = B^2 \sigma = \frac{P m}{2},$$

and the application correspondingly adapted. In illustration of the preceding formulæ the behaviour of the permanent way of the

---

[1] The moments of inertia I, I_1, I_{11}, modulus of elasticity E and coefficients C, σ, m, were given generally in the original metric measure, the centimetre being the unit of length, the kilogram that of weight.

To obtain the equivalent values for English standards, the units being the inch and pound, multiply

I, I_1, I_{11} by $\frac{1}{(2·54)^4}$;
E „ $2·205\,(2·54)^2$;
C „ „ „
σ „ „ „

m was merely an abbreviation for convenience in calculation.

1 inch = 2·54 centimetres; 1 kilogram = 2·205 lbs.

Digitized by Google

Berliner Stadtbahn upon different kinds of ground, denoted and characterised by the coefficients of elasticity C = 2, 3, 4, 8 (28·38, 42·57, 56·76, 113·52), would be numerically calculated in the sequel. Mr. Schwedler.

This system of permanent way had been represented in Fig. 16. In this case the moment of inertia of the worn-out rail $I_1 = 570$, the height of the centre of gravity of its cross-section $e = 5{\cdot}7$ ($2\frac{1}{4}$ inches), the moment of inertia of the longitudinal sleeper $I_{11} = 130$; consequently $I = I_1 + I_2 = 700$. The width B of the sleeper was 32 centimetres (12·6 inches).

The results, if P = 7,000 kilograms (15,432 lbs.),
E = 2,000,000 „
were—

for C =	2	3	4	8	
$\frac{1}{m}$ =	97	88	81	65	
$M = \frac{P}{4m}$ =	170,000	154,000	142,000	114,000	kg. cm.
	(147,492)	(133,610)	(123,199)	(98,947)	inch lbs.
$p = \frac{2P}{m}$ =	35	40	43	54	kg. per lineal cm.
	(196)	(224)	(240·8)	(302·4)	lbs. per lin. in.
$k = \frac{Me}{I}$ =	1,385	1,254	1,145	929	kg. per sq. cm.
	(19,699)	(17,836)	(16,285)	(13,213)	lbs. per sq. in.
$\sigma = \frac{p}{B^2}$ =	0·035	0·039	0·042	0·052	

For Hilf's system of permanent way, Fig. 10, if a high rail with $e = 5{\cdot}8$ centimetres (2·28 inches) was used, the following figures would be obtained:—

$I_1 = 680$, $I_{11} = 70$, $I = 680 + 70 = 750$, $B = 30$,

for C =	2	3	4	8
$\frac{1}{m}$ =	100	90	84	70
M =	175,000	157,500	147,000	122,500
	(151,892)	(136,704)	(127,590)	(106,325)
p =	35	39	42	50
	(196)	(218·4)	(235·2)	(280)
k =	1,351	1,218	1,137	945
	(19,215)	(17,324)	(16,171)	(13,441)
σ =	0·039	0·043	0·047	0·055

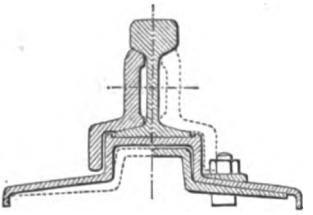
Digitized by Google

Mr. Schwedler. As both systems of permanent way were satisfactory as regarded vertical loads, it would be desirable, for rough calculations, to take $k = 1{,}200$, $\sigma = 0{\cdot}04$; and for a given value of P, and assuming B, to determine the values of I and e, then after choice of I_{II} to calculate I_I and construct the rail in accordance with e.

In construction the following conditions must be fulfilled that the result might correspond with the calculations:—

1. The rail and sleeper must be fished at the joints, and the fish-plates should have approximately the same moment of inertia as the rail or sleeper, so that the deflection of the permanent way, upon which the action on the ballast depended, might be everywhere equal, and no sagging occur at the joints. If it was possible to make the fish-plates $4\frac{3}{4}$ to $5\frac{1}{2}$ inches high, as in Fig. 16 and Fig. 61, where the form of the sleeper permitted, the rail could be covered by the rail fish-plate only, and the sleeper by the sleeper fish-plate, and the junctions of each part of the structure might alternate. If the form of sleeper was such that the rail fish-plate could not be made so high, as in Figs. 9, 10, 11, and 12, the rail fish-plate alone would not suffice to cover the rail, and the sleeper fish-plate must be made stronger to such extent that the fish-plates together had the moment of inertia $I_I + I_{II}$. In this case rail and sleeper must be fished at the same point, and the form shown in Fig. 10 would result.

Fig. 61. Fig. 62.



2. The longitudinal sleeper must have approximately vertical turned-down flanges at the edges to prevent the bedding from spreading out under the smooth surface of the sleeper, and to maintain sufficient friction. In the absence of flanges the sleeper sank more readily, the ballast was more easily displaced, and the resistance of the ground diminished, and this necessitated a coefficient σ smaller by about one-half for substitution in the calculation (Figs. 1, 3, 4, 5, 6, 7, 8, 15). On the other hand the coefficient might be increased if the way could be ballasted, outside the rails at least, up to the top of the latter, and the sleepers penetrated deep into the ground.

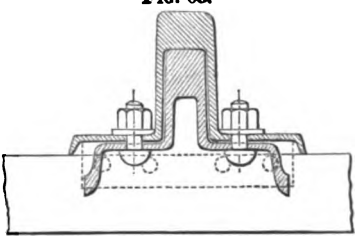
3. To ensure a good fit between the fish-plates and the rails it was advisable not to make the inclination of the surfaces of contact with the horizon greater than 1 : 4, the fish-plates $23\frac{1}{2}$ inches long or more, and if practicable to insert between the surfaces of contact at the ends of the rails and fish-plates steel plates 0·04

Digitized by Google

inch thick, that at these points only contact might be made with the fish-plates, and that at other parts the fish-plate and rail might not touch. The sleeper fish-plates should only be applied underneath, and should be attached to the sleepers by eight vertical bolts. The bolts should have double-threaded screws (Fig. 62), and each of the upper washers for the nuts should be common to four bolts, so that on a change of temperature the bolts might not cant and become strained and loosened. Mr. Schwedler.

He considered permanent way made in single pieces preferable on the score of economy, solidity, and stability. The form designed by Mr. Barlow in 1849, Fig. 1, should however be somewhat modified, as shown in Fig. 63, in which the foot was 10 inches wide, the total height 5·9 inches, including the flanges, 0·79 inch, the web and foot flanges 0·31 inch thick, at the corners 0·39 inch, and rounded off, and the head 1·58 inch thick and 2·36 inches. The moment of inertia was about I = 1,000, the height of the centre of gravity when 0·8 inch had been worn off about 2·76 inches = e, the weight 92·59 lbs. per metre. Where the ballast was coarse the hollow space might be filled with wood. The buckling of the horizontal flanges might be prevented by short angle-irons riveted below at intervals of 3 feet. The latter obviated longitudinal displacement, and could be used for attaching transverse connections of bar iron on edge at intervals of 12 feet. For curves the rails must be bent on leaving the rolls. Fish-plates of the same moment of inertia, as shown in Fig. 63, and of sufficient length should be attached by eight bolts. The rolling of this sleeper, however, presented difficulties. When rail and sleeper were separate it was economical to give the requisite moment of inertia principally to the rail, and to construct the sleeper more as a plate with flanges under it, as the moment of inertia of the rail, which had only a single web, could be increased with less expenditure of material than that of the sleeper, which in general must be kept low, and was made with two webs, as in Haarmann's system.

FIG. 63.



The difficulty was that a rail with a great moment of inertia required a similar fish-plate, and this could not be used on account of the projected plate. All that remained to be done in this case was to utilise the strength of the sleeper fish-plate for the rail by

Digitized by Google

Mr. Schwedler. making the junctions of the rails and of the sleepers coincide. This suggested the form shown in Fig. 64, which had not been carried out in practice, but was a development of Fig. 10, the latter being constructed for Hilf's sleeper. On a considerable length of the Ostbahn a similar system of fish-plates of greater strength, for Hilf's sleepers, had come into use (Fig. 65).

FIG. 64.

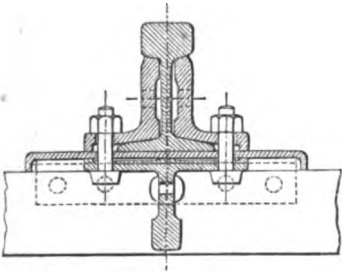
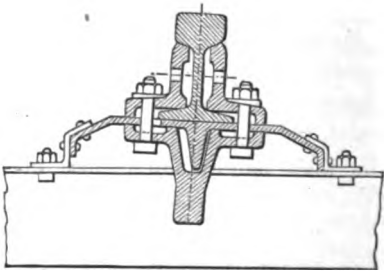


FIG. 65.



Haarmann's sleeper, which had resulted from the intention of increasing the moment of inertia and making use of clamp connections, had been adopted because the rails could have fish-plates 5·11 inches high, and it was thus possible for sleepers and rails to overlap. The wear and tear of the joints was thereby somewhat reduced. The high position of the rail on the Haarmann sleeper, which was only 10·23 inches wide, had been rendered less objectionable by widening the foot of the sleeper to 12·6 inches. Neither the sleeper nor rail fish-plates were shown in Fig. 16, but only the recesses for attaching the transverse connections. The latter, on curves, were not always at right angles opposite to each other as the joints of the inner line in being laid were in advance, until in the outer line a longer rail and sleeper was inserted. To avoid undue strains in this case the transverse connections were attached with only one bolt. This connection, in curves on freshly-laid ballast, was insufficient. The force with which the leading wheel of the locomotive pressed against the outer rail was about $\frac{1}{18}$ of the weight of the locomotive (half the friction of the total weight of the locomotive $\frac{Q}{12}$ less that of the leading front wheel $\frac{Q}{36}$), or, say, 2·4 tons, and the transverse connection in its low position could not support this resistance without considerable deflection. To avoid an increase of the gauge, and to facilitate

Digitized by Google

the regular formation of the consolidated bed on which the sleepers rested, tie-rods, as in Hilf's system, Fig. 9, had been used on the Berlin Stadteisenbahn. These, together with the transverse connections, served better to distribute the horizontal pressure between the two lines of rail, and to maintain the gauge as well as the inclination of the rails. The use of transverse sleepers under the joints of longitudinal sleepers (Fig. 9) had latterly been abandoned; it altered the conditions of elasticity of the system, and gave rise to irregularities. Mr. Schwedler

Multiple systems had mostly been invented with the object of keeping the rail, as the perishable portion, small, so as to incur slighter losses in renewal. This reduction of the height of the rails was, however, not desirable; under traffic the head was strongly compressed and stretched longitudinally and laterally, and these stresses must be held in equilibrium by the web and flange of the rail. With rails too low deflections soon loosened the connections. The whole resistance was thus thrown upon the sleeper, in which continuity was difficult, if not impossible, to establish by fish-plates of equivalent strength.

In the latter case irregularities were caused in the compression of the ballast, which was then often loosened by frequent repairs, causing still greater irregularities. It was desirable that the transverse connections should not coincide with the joints. Tie-rods alone were insufficient, as they did not ensure the required inclination of the rails. These should unite the two lines of rail, not too far below the top of the latter, so rigidly that with an imperceptible deflection they should distribute the pressure exerted by the wheel-flange (which was not vertical, but might deviate in the ratio 1 : 2 from the vertical) vertically upon the centre of the sleeper, and thus produce a uniform consolidation of the ballast. From this uniform consolidation arose the drawback that the ballast under the sleepers became impervious to water, and the latter collected between the rails, and in frosty weather caused irregularities in the line, and in mild weather, on the other hand, softened the foundations. Hence a good method of drainage, longitudinally by a drain pipe, transversely by gullies of masonry, should be associated with longitudinal sleepers.

This circumstance, as well as the difficulty of removal in altering the permanent way, had deterred many engineers from adopting the system, or had led them to return to transverse sleepers. Nevertheless, where railways were not of a temporary character, and a substantial system of drainage could be established, or where the ballast was of a permanently porous character, even

Digitized by Google

Mr. Schwedler. after it had been compressed into a state of elastic cohesion, the longitudinal sleeper system, in economy of maintenance and excellence and durability in the equality of the road, had essentially the same superiority over the transverse sleeper system as a firm smooth asphalt road had over wooden paving. The so-called hard running, perceptible by the high pitch of the vibrations, which resulted from the greater coefficient of elasticity of the consolidated ballast, was, on account of the smaller amplitude in the oscillations of the vehicles, less detrimental than soft running on elastic transverse sleepers, when the position of the latter was not quite uniform, and isolated irregularities gave rise to excessive oscillations and shocks which altered the form of the supporting ballast.

To explain clearly the action of the vehicles on the ballast in the longitudinal sleeper system, it would be necessary to go somewhat further into the theory previously indicated, and the measurements which substantiated it.

The differential equation—

$$E I \frac{d^4 y}{d x^4} = - C B y$$

corresponded to the function

$$y = \frac{P m}{2 C B} \cdot e^{-m x} (\sin m x + \cos m x) = \frac{P m}{2 C B} \eta$$

in which $m = \sqrt[4]{\frac{C B}{4 E I}}$, and which represented the elastic line of the rail and sleeper. Taken negatively, it also gave the distribution of pressure on the ballast, since $p = - C B y$. The second differential of this quantity, according to x, gave the bending moment of rail and sleeper, taken together,

$$M = \frac{P}{4 m} e^{-m x} (\sin m x - \cos m x) = \frac{P}{4 m} \mu.$$

In practice the variable portion which represented a particular function was denoted by η and μ respectively. In Fig. 66 both functions η and μ were represented. They were periodical, like the quantities $\sin m x$ and $\cos m x$, which varied between the values $+ 1$ and $- 1$, when $m x$ was a multiple of $\Pi = 3{\cdot}14 \ldots$ or $\frac{\Pi}{2} = 1{\cdot}57 \ldots$. The period of η varied from $m x = o$ to $m x = \Pi$, that of μ from $m x = \frac{\Pi}{2}$ to $m x = \frac{3}{2} \Pi$, where each time a maximum was alternately negative and positive. If the distance between two

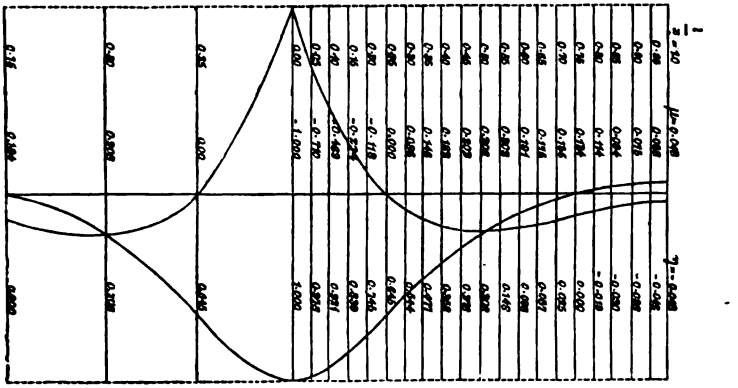
Digitized by Google

such points was denoted by l, that was the distance between the hollow and crest of a wave, then $l = \frac{\Pi}{m} = \Pi \sqrt[4]{\frac{4\,E\,I}{C\,B}}$. Mr. Schwedler

The values of η and μ were in every successive interval l, $e\Pi = 0{\cdot}043 = \frac{1}{23}$ of those in the preceding of the opposite sign. Hence the interval o to l in front of and behind the load must be known in order to calculate all the ordinates and plot them symmetrically. The twenty ordinates given allowed the accurate delineation of the curves and their continuation, until sufficiently small values were reached, for the purpose of scaling off all values of η and μ, from which y and M could be determined.

FIG. 66.

Curve of moments $\mu = e^{-mx}(\sin mx - \cos mx)$; $ml = \Pi$.



Elastic line $\eta = e^{-mx}(\sin mx + \cos mx)$; $ml = \Pi$.

To obtain the elastic line for several wheels a single vehicle, or a whole train, it was only necessary to draw these curves for every load in the position corresponding to the latter, and then to sum up the ordinates which coincided according to their signs (positive or negative). Or, if the loads were distant from a given point by the lengths x_1 x_{11} x_{111}, etc. (taken positively both backwards and forwards), then for this point

$$y = \frac{P\,m}{2\,C\,B} \cdot (\eta_{x_1} + \eta_{x_{11}} + \eta_{x_{111}}, \text{ \&c., and}$$

$$M = \frac{P}{4\,m}(\mu_{x_1} + \mu_{x_{11}} + \mu_{x_{111}}, \text{ \&c.}).$$

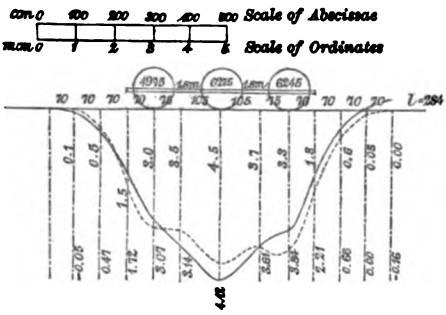
If, for instance, $m = \frac{1}{91}$, $l = 286$ centimetres (9 feet 4·6 inches), $x = 100$ centimetres (3 feet 3·37 inches), then $x = \frac{100}{286}\,l = 0{\cdot}35\,l$,

Digitized by Google

Mr. Schwedler. and according to the above diagram and table $\eta_{x_1} = 0{\cdot}447$, $\mu_{x_1} = 0{\cdot}146$.

On the Alsace-Lorraine Railway a measurement of the deflection of the rail of Hilf's permanent way, at a given point, relative to another fixed point some distance off, had been made during the passage of vehicles pushed over it. The dimensions of the permanent way were:—B = 11·81 inches, $I_1 + I_{11} = 659 + 113 = 772 = I$.

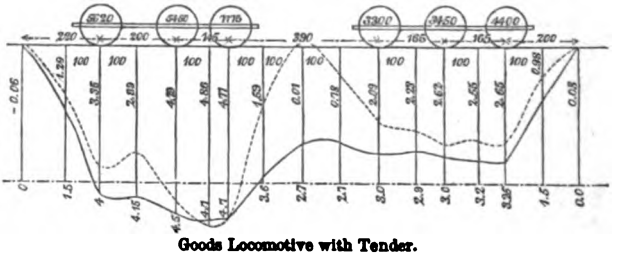
FIG. 67.



6-wheeled Tank Locomotive.
The weights in the wheels are in kilograms, and the intervals between them are in centimetres.

In Figs. 67, 68, 69, 70, the results of the measurements were shown, the loads on the wheels being given. The dotted lines had been calculated by the preceding method. In this case the value C = 3 had been

FIG. 68.



Goods Locomotive with Tender.

FIG. 69.

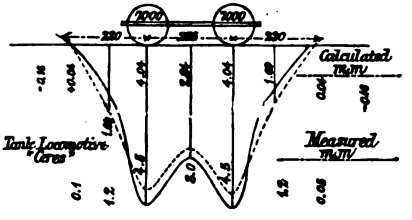
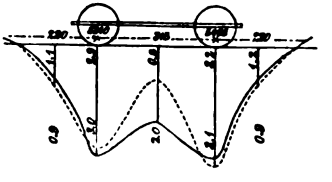


FIG. 70.



Tender.

assumed, hence C B = 90, E = 2,000,000, $\frac{1}{m} = 53{\cdot}2\sqrt{\frac{772}{90}} = 91$, $l = \frac{\Pi}{m} = 286$ centimetres (9 feet 4·6 inches).

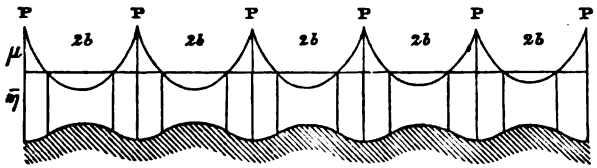
In general the agreement between the measured and the calculated ordinates pointed to the conclusion that the theory was correct; in applying it differences occurred only at the few points where the rails rose above the level, as here the weight of the

Digitized by Google

permanent way was in part less than the required negative pressure of the ground p. These differences, however, had little influence on the maximum deflections and moments. The large divergences at points between the wheel-loads led to the conclusion that the reaction of the ballast during compression followed the law of elasticity, but that the recoil took place more slowly, and with less energy. This property of the ballast agreed with that of other solid bodies, compressed rather beyond the limit of elasticity, as the latter only regained their original form after some time had elapsed. Mr. Schwedler

To form a judgment as to the transverse sleeper system, it would first be necessary to demonstrate the results of the theory of elasticity as applied to transverse sleepers. The elastic line y and the curve of moments M, for the transverse sleeper, might be derived from the lines shown for the longitudinal sleeper. Let a longitudinal sleeper be imagined, with an unlimited series of equal loads, P placed alternately at the distances $2a$ and $2b$ from each other, and the elastic line and curve of moments of this sleeper

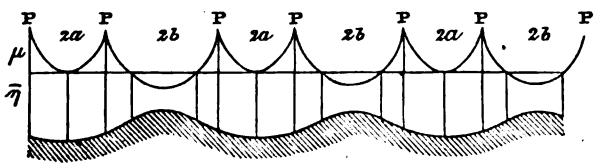
FIG. 71.



calculated by the method of summing up for the respective points a, o, and b. If the intervals $2a$ and $2b$ were all equal to $2b$, y must be a regular wave line, as shown in Fig. 71, similar to an infinitely long girder, uniformly loaded and supported at equal intervals.

The line of moments consisted of a series of curves bent downwards, which intersected the axis of abscissæ twice between every two loads, where the moment was nil and y had a point of inflection. If, however, $2b$ was greater than $2a$, y ascended higher in the interval $2b$, and descended lower in $2a$; M, on the other hand, was lower in $2b$ and higher in the centre in $2a$.

FIG. 72.



For a certain ratio of $2a : 2b$ (Fig. 72) it must therefore happen that M touches the axis of abscissæ in the centre of $2a$; that was,

Digitized by Google

Mr. Schwedler. M became nil at this point, and at the same time attained a minimum, whereby the transverse force acting on the sleeper disappeared.

Now, as in these points there was no stress in the sleeper, neither a transverse force nor a bending moment, the sleeper might here be cut through without altering the condition of any other section. The longitudinal sleeper was thus converted into a series of transverse sleepers of the length $L = 2b + 2a$, on which rested the two loads, P, at a distance $2b$ apart; $2b$ was the width of gauge. A transverse sleeper of this length, which might be called normal, was so placed that at both ends the lowest position coincided with a horizontal tangent. Of course the greatest pressure on the ballast also occurred there, while the greatest bending moments took place under the loads and in the middle. If the ratio $2a : 2b$ was greater or less than in the case of the normal sleeper, on cutting through the sleeper in the centre of $2a$, a positive or negative moment of resistance would be destroyed, and the further deflection of the sleeper was such as would be caused by the neutralised M. The lines of deflections and moments hence required in this case a correction, which, added to the ordinates of M, made M at the end equal to nil. If, for instance, the neutralised moment at the end had been M_a, the moments, as represented by the curve of moments at the distance x from each end, had been diminished approximately by the amount $\Delta M = M_a e^{-mx} (\sin mx + \cos mx)$; that was according to the law of the elastic line for the longitudinal sleeper. The deflections Δy, on the other hand, increased nearly by $\Delta y_a = M_a \frac{2m^2}{C B} e^{-mx} (\sin mx - \cos mx)$, that was according to the law of the curve of moments. As the curves referred to might easily be drawn from the figures; the combinations and corrections might also be easily determined graphically. For the normal length of sleeper, a was the portion of the transverse sleeper which projected beyond the rail, and $ma = \frac{\Pi}{4}$, or $a = \frac{\Pi}{4m} = \frac{l}{4}$ might be taken with sufficient accuracy.

The total length of the normal transverse sleeper was therefore $L = 2b + \frac{l}{2}$, or

$$L = 2b + \frac{\Pi}{2m} = 2b + \frac{\Pi}{2} \sqrt[4]{\frac{4EI}{CB}}.$$

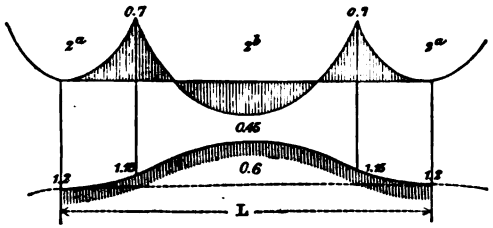
For $C = 3$, $B = 25$ (9·84 inches), $I = 75$, $E = 2{,}000{,}000$, for instance, there resulted $\frac{1}{m} = 53$, $l = \frac{\Pi}{m} = 167$ centimetres (5 feet 5·7 inches),

Digitized by Google

$a = 41$ (1 foot 4·4 inches), and $L = 150 + 2 \cdot 41 = 232$ (7 feet 7·3 inches).

In Fig. 73 the elastic line (being also the curve of the ground pressure) was represented for the normal transverse sleeper.

Fig. 73.



Under average conditions the ground pressure at the ends was approximately—

$$P_a = 1 \cdot 2 \frac{P\,m}{2},$$

in the centre $P_b = 0 \cdot 6 \frac{P\,m}{2}$,

under the rails $P_c = 1 \cdot 15 \frac{P\,m}{2}$;

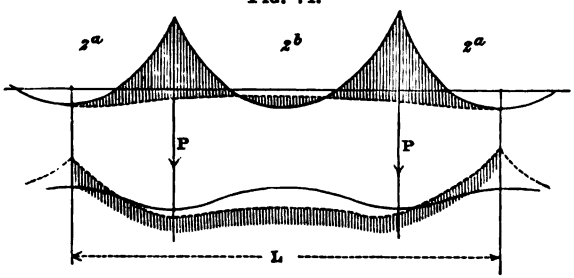
the bending moment—

under the rails $M_c = -0 \cdot 70 \frac{P}{4\,m}$,

in the centre $M_o = +0 \cdot 50 \frac{P}{4\,m}$.

If the length of L was taken as greater than for the normal transverse sleeper, the pressure of the ground at the ends became smaller (Fig. 74), and the condition might be imposed that the

Fig. 74.



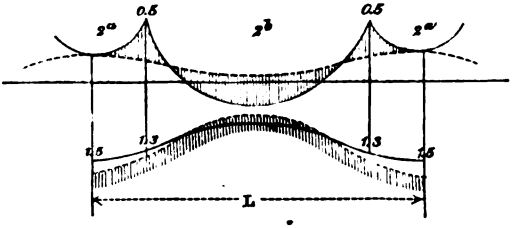
pressure at the ends and in the middle should be equal. This would occur approximately if $a = \frac{5}{16}\,l$, when $L = 150 + \frac{5}{8}\,l$.

Digitized by Google

Mr. Schwedler. In a sleeper for secondary railways, where $l = 167$ (5 feet 5·7 inches), I = 75, C = 3, B = 25 (9·84 inches), there resulted L = 150 + 105 = 255 (8 feet 4·4 inches). This might be called the long transverse sleeper.

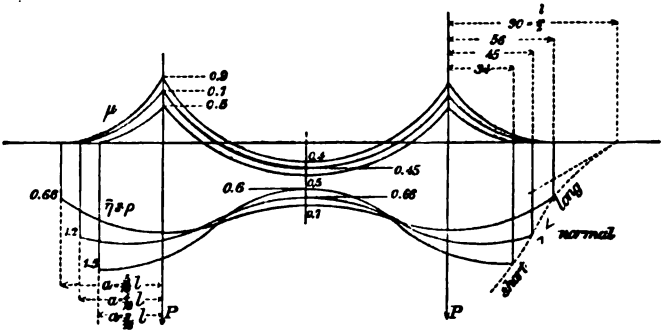
With a smaller length than that of the normal transverse sleeper,

Fig. 75.



the ground pressure at the ends, and the deflection in the middle, increased (Figs. 75 and 76); and the condition might be imposed that

Fig. 76.



L = 262, 240, 218 c.m.

Diagrams of long, normal, and short transverse sleepers.

the bending moment under the rails and in the centre should be equal. This would be the case for $L = 150 + \frac{3}{8} l$ nearly. In a special case the numerical values stated in the diagrams of η_a η_c and η_b, or $\frac{p_a}{P\,m}$; $\frac{p_c}{P\,m}$; $\frac{p_b}{P\,m}$ could eventually be corrected, by help of the condition that the mean ground pressure $P_{med.}$ multiplied by L must be equal to 2 P. It involved, however, no great labour to determine accurately the numerical values by help of the graphical table, Fig. 6, when a and b were arbitrarily assumed, and m

Digitized by Google

and l known. The exact method was given by the following formulæ:— Mr. Schwedler.

1. Ground pressure at the ends of the sleeper:

$$p_a = \frac{P\,m}{2}\left[2\,\eta_a + 2\,\eta_{a+2b} + 2\,\eta_{3a+2b} + 2\,\eta_{3a+4b} + \ldots\right.$$
$$\left. + \frac{1+2\,\mu_{2\,(a+b)}}{1+2\,\eta_{2\,(a+b)}}\,(2\,\mu_a + 2\,\mu_{a+2b} + 2\,\mu_{3a+2b} + 2\,\mu_{3a+4b} + \ldots.)\right].$$

(Where a, $a+2b$, &c., should be expressed as multiples of l, the corresponding values for η_a η_{a+b} μ_a, &c., being then taken from the table, Fig. 66. Their sum, having regard to the signs positive or negative, gave the ordinates shown in Figs. 73, 74, and 75, from which, after multiplication with $\frac{P\,m}{2}$ (the ground pressure under the wheel in the longitudinal sleeper system) yielded the value P_a.

2. Ground pressure under the rail supports:—

$$p_a = \frac{P\,m}{2}\left[1+\eta_{2a}+\eta_{2b}+\eta_{2a+2b}+\eta_{4a+2b}+\eta_{2a+4b}+\eta_{4a+4b}+\ldots\right.$$
$$\left. + \frac{\mu_a+\mu_{2b+a}+\mu_{2b+3a}+\ldots.}{1+2\,\eta_{(3a+2b)}+\ldots}\cdot\{2\,\mu_a+2\,\mu_{2b+a}+2\,\mu_{2b+3a}+\ldots\}\right].$$

3. Ground pressure in the centre of the sleepers:—

$$p_b = \frac{P\,m}{2}\left[2\,\eta_b + 2\,\eta_{b+2a} + 2\,\eta_{2b+2a}\ldots + \frac{2\,\mu_{a+b}+2\,\mu_{2a+2b}}{1+\eta_{2a+2b}}\cdot\right.$$
$$\left.\{2\,\mu_a+2\,\mu_{2b+a}+2\,\mu_{2b+3a}+\ldots\}\right].$$

4. Bending moment under the rail:—

$$M_a = \frac{-P}{4\,m}\left[1+\mu_{2a}+\mu_{2b}+2\,\mu_{2a+2b}+\mu_{4a+2b}+\ldots\right.$$
$$\left. - \frac{\eta_a+\eta_{2b+a}+\ldots}{1+2\,\eta_{2a+2b}}\cdot\{2\,\mu_a+2\,\mu_{2b+a}+2\,\mu_{2b+3a}+\ldots\}\right].$$

5. Bending moment in the centre of sleeper:—

$$M_b = \frac{-P}{4\,m}\left[2\,\mu_b + 2\,\mu_{b+2a} + \mu_{2b+2a} + 2\,\mu_{2b+4a}+\ldots\right.$$
$$\left. - \frac{2\,\eta_{a+b}+2\,\eta_{3a+2b}}{1+2\,\eta_{2a+2b}}\cdot\{2\,\mu_a+2\,\mu_{2b+a}+2\,\mu_{2b+3a}+\ldots\}\right].$$

The second portions of the formulæ disappeared for the normal transverse sleeper, as they became nil. In the long and short

Digitized by Google

Mr. Schwedler. sleepers they gave the correction previously mentioned. It should be remarked that the load P, in the case of the transverse sleeper, should not be made equal to the pressure on the locomotive wheels (7,000 kilograms), but be smaller, as, in consequence of the rigidity of the rails, the neighbouring sleepers assisted in carrying the load. If the pressure of the wheels was taken as R = 7,000 kilograms, or 5,000 kilograms, then—

$$P = R\,\frac{n+1}{n+3} \text{ where } n = \frac{\lambda^3}{3\,E\,I_1}\cdot\frac{2\,C\,B}{m\{1+\eta_{3a}+\eta_{2b}+\eta_{3a+b}\ldots\}},$$

where I was the moment of inertiæ of the rail, E, the modulus of elasticity of the material of which it was made, and λ the distance of the sleepers from each other. The values of m, B, η related to the sleeper. For R = 7,000 and I_1 = 900, C = 3, B = 25 centimetres (9·84 inches) $(\Sigma\,\eta)_a = 1{\cdot}16$, $m = \frac{1}{58}$, $\lambda = 100$, E = 2,000,000, the value of $n = 1{\cdot}61$, and P = 4,102 kilograms (9,043·3 lbs.).

If the coefficient of elasticity of the ballast was greater, say C = 8, then $m = \frac{1}{45}\,(\Sigma\,\eta)_a = 1{\cdot}05$, $n = 3{\cdot}2$, P = 4,760 kilograms (10,493·87 lbs.) for the Prussian iron transverse sleeper of normal length, L = 240 centimetres (7 feet 10½ inches), I_{11} = 105.

For the cross-sections of the latter with reference to the preceding calculation, a pressure P = 5,000 kilograms (11,023 lbs.) for a wheel-pressure R = 7,000 kilograms (15,432·2 lbs.) had been assumed.

If the old Rhenish iron transverse sleeper, the Vautherin system (Fig. 21) was made the subject of calculation, the data would be L = 230 centimetres (7 feet 6½ inches), I_{11} = 81, B = 22 centimetres (8·66 inches), weight 35 kilograms (77·16 lbs.) each, and the values assumed C = 3, E = 2,000,000; the results would then be C B = 66, $\frac{1}{m}$ = 56, l = 176 (5 feet 9·2 inches), $(\Sigma\,\eta)_a$ = 1·32 $(\Sigma\,\eta)_a$ = 1·24; $(\Sigma\,\eta)_b$ = 0·59; $(\Sigma\,\mu)_a$ = 0·7, $(\Sigma\,\mu)_b$ = 0·5.

$$M_a = \frac{5{,}000 \times 56}{4}\,0{\cdot}7 = 49{,}000 = \frac{I_{11}\,K}{e}\ (42{,}529 \text{ inch-lbs.});$$

$$K_a = \frac{49{,}000 \times 3{\cdot}7}{81} = 2{,}238 \text{ kilograms per square centimetre (31,831 lbs. per square inch).}$$

$$M_b = \frac{5{,}000 \times 56}{4}\,0{\cdot}5 = 35{,}000\ (30{,}379 \text{ inch-lbs.}) = \frac{81}{3{\cdot}7}\,K;\ K_b = 1{,}602\ (22{,}785 \text{ lbs. per square inch}).$$

Digitized by Google

Mr. Schwedler.

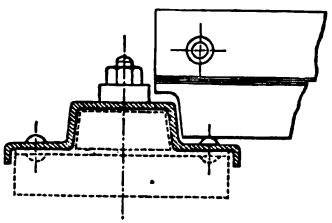
$$p_a = \frac{5{,}000 \times 1{\cdot}32}{56 \times 2} = 59\,;\ \sigma_a = \frac{59}{22^2} = 0{\cdot}122.$$

$$p_o = \frac{5{,}000 \times 1{\cdot}24}{56 \times 2} = 55\,;\ \sigma_o = \frac{55}{22^2} = 0{\cdot}113.$$

$$p_b = \frac{5{,}000 \times 0{\cdot}59}{56{\cdot}2} = 26{\cdot}3\,;\ \sigma_b = \frac{26{\cdot}3}{22^2} = 0{\cdot}055.$$

Considering that in the case of longitudinal sleepers the constant for the ground σ was taken at 0·04, and that with C = 3 no greater strain than 1,200 kilograms per square centimetre (17,068 lbs. per square inch) was assumed for the iron, the values obtained, K = 2,238 and σ = 0·122, must be deemed unfavourable, as the sleepers would be partly bent and partly subside. An increase of width to B = 27 centimetres (10·63 inches) would only reduce K to 1,982 (28,190 lbs. per square inch), and σ to 0·077. For the newly ordered iron transverse sleepers, T_{11} had therefore been increased to 105, thereby maintaining the required economy. Fig. 78, similar to the Haarmann pattern, was the result. The upper plate was 11 centimetres (4·32 inches) wide and 0·9 centimetre (0·35 inch) thick. The centre of gravity lay 3·8 centimetres above the lower flanges, which were 2 centimetres (0·79 inch) deep. Their weight was about 110·23 lbs. each. At the ends and in the middle vertical transverse ribs were riveted on. The length was that of a normal transverse sleeper L = 240 (7 feet 10½ inches)—

FIG. 78.



$$\frac{1}{m} = 57{\cdot}8,\ l = 182,\ (\Sigma\eta)_a = 1{\cdot}168\,;\ (\Sigma\eta)_o = 1{\cdot}161\,;$$

$$(\Sigma\eta)_b = 0{\cdot}58,\ (\Sigma\mu)_a = 0{\cdot}728,\ (\Sigma\mu)_b = 0{\cdot}502\,;\ P = 5{,}000\ (11{,}023\ \text{lbs.})$$

$$M_a = \frac{P}{4m}(\Sigma\mu)_a = 52{,}597 = \frac{105}{3{\cdot}8}K\,;\ K_a = 1{,}900\ (27{,}024\ \text{lbs. per square inch}) \text{ below.}$$

$$= \frac{105}{2{\cdot}6}K\,;\ K_a = 1{,}315\ (18{,}703\ \text{lbs. per square inch}) \text{ above.}$$

$$M_b = \frac{P}{4m}(\Sigma\mu)_b = 36{,}267 = \frac{105}{3{\cdot}8}K\,;\ K_b = 1{,}313\ (18{,}675\ \text{lbs. per square inch}) \text{ below.}$$

$$= \frac{105}{3{\cdot}8}K\,;\ K_b = 906\ (12{,}886\ \text{lbs. per square inch}) \text{ above.}$$

Digitized by Google

Mr. Schwedler.

$$p_a = \frac{P m}{2} (\Sigma \eta)_a = 55 \text{ kilograms}; \quad \sigma_a = \frac{55}{25^2} = 0{\cdot}088.$$

$$p_o = \frac{P m}{2} (\Sigma \eta)_o = 52 \quad ,, \quad \sigma_o = \quad = 0{\cdot}083.$$

$$p_b = \frac{P m}{2} (\Sigma \eta)_b = 25 \quad ,, \quad \sigma_b = \quad = 0{\cdot}040.$$

An increase in the width of the sleeper to 27 centimetres (10·33 inches) would in this case also merely reduce the preceding quantities to 1,874, 1,230, 1,300, 860, 0·068, 0·065, and 0·039 respectively. From this it appeared, that, preserving the same degree of economy, the transverse sleeper permanent way did not give such favourable results as the longitudinal sleeper system. In the section shown in Fig. 78 the intention was, while obtaining a large moment of inertia, to keep the centre of gravity as low as possible, to reduce the stress K. As constructed with the flanges, although the latter were but 1·5 centimetre (0·59 inch) deep, this had only partially succeeded. Nevertheless the form was in so far good, that the greatest stress was confined to the edges; and, in case of the latter being wrenched, the wide footplate sustained the maximum stress, and the conditions became more favourable. By strengthening the footplate and reducing the upper plate, with equal economy and preserving the same value of I_{11}, a lower position of the centre of gravity would be attained and the coefficient K reduced; in which case washers for the rail bearers would be necessary. The latter could, however, be advantageously used to give the inclined position to the rails, now done by bending the sleepers.

It was a peculiarity of transverse as compared with longitudinal sleepers, that the former were always loaded at the same point (Fig. 22), while in the latter the load rolled. With longitudinal sleepers, therefore, the ground was uniformly compressed and consolidated by continuous uniform rolling, while with transverse sleepers it was only plastically pressed, and thereby assumed the form of the elastic line of the transverse sleeper. Hence in transverse sleepers, the coefficient of elasticity could not well be taken as greater than 3, because in fresh ballast the shape when set was formed. The accuracy of the calculation for the maximum deflection was little affected by this, but the sleeper did not rest firmly under the rails, nor probably the ends, if the pressure of the wheel was not the maximum pressure. In the transit of passenger carriages the so-called easy running arose from the hollow beneath the sleepers.

The greater the hollow the more easily was the line displaced. A remedy consisted in deeply bedding the sleeper, but then, as

Digitized by Google

in Haarmann's system (Fig. 23), the horizontal component of the flange pressure on the curves of the line produced a greater deflection of the sleeper in soft ballast, in consequence of the high level of the rails. Thus the firm bedding of the sleeper was neutralised by the high position of the rails. The hollow space under the ends of the sleepers increased with the height of the rails above the latter, the reduction of the length of the sleepers and the softness of the ballast. It would be an improvement if the ballast were previously compressed, or long transverse sleepers used. The latter would rest uniformly in the middle and at the ends, and only have the hollow space (in this case desirable) under the rails, which would combine security of position with easy running. Mr. Schwedler.

The best method of attaching the rails to the cross sleepers had not yet been settled; it would seem, however, that with iron sleepers, as compared with the spike-attachment for wooden sleepers, too much was often attempted. In Prussia the Rhenish system of attachment (Figs. 21 and 22) was mostly used, for rails with flanges of from 4 to 4⅛ inches. It would be desirable so to arrange the attachment, as to exclude the possibility of its working loose, and enable the sleepers to be covered with ballast up to the head of the rail.

If the usual wooden sleeper with L = 250 (8 feet 2½ inches), a depth of 15 centimetres (5·9 inches), and a width of 25 centimetres (9·84 inches) was compared with the iron cross sleeper, it would be seen that the ballast could slip out of place against the smooth under-surface with greater facility, on account of the absence of flanges. With the same coefficient σ the wooden sleeper was therefore at a disadvantage. Its moment of inertia was I = 7,000, the modulus of elasticity E = 120,000 kilograms, C B = 3 × 25 = 75; hence $\frac{1}{m}$ = 81 and l = II 81 = 254. With the normal length, L should be = $\frac{150}{2}+254=277$ centimetres, having a length of 250 centimetres, it consequently belonged to the short sleepers, which were strongly deflected at the ends, lay hollow, and sustained the greatest ground pressure. A rough calculation gave the following results:—

$$p_e = \frac{5{,}000}{2 \times 81} \times 1{\cdot}5 = 46 \text{ kilograms } (101{\cdot}41 \text{ lbs.}) = \sigma \times 25^2;$$
$$\sigma_e = 0{\cdot}073.$$

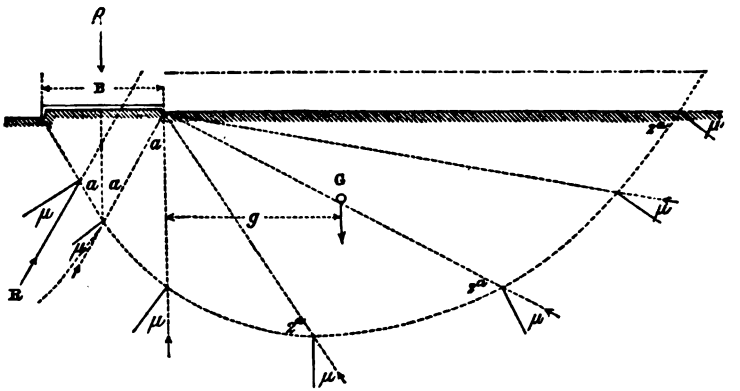
$$M_e = M_b = \frac{5{,}000 \times 81}{4} \times 0{\cdot}5 = 50{,}625 (43{,}920 \text{ inch-lbs.}) = K \frac{7{,}000}{7{\cdot}5};$$

K_e = 54 kilograms per square centimetre (768 lbs. per square inch).

Digitized by Google

Mr. Schwedler. It was desirable that p_e should be rather less, while K_e might be somewhat greater. An improvement would take place with a slight reduction in the height and increase of the length and width. It appeared from this that wooden transverse sleepers compared with those of iron, were, as regarded the coefficients K and σ, not unfavourable, only they did not oppose the same resistance to longitudinal displacement as iron cross sleepers with three transverse ribs (one in the middle and two at the end), and, on account of the absence of flanges, did not hold the ballast firmly together. In further discussing the theoretical aspect of the ballast bed, and the equation $p = B^2 \sigma$, as a basis to start from, a homogeneous material, without cohesion and more or less rough, would be taken. It was usual to measure the roughness by the angle of repose μ, so that the coefficient of friction within the material was $tg.\ \mu = \rho$. If the sleeper was laid on the horizontal surface of the material (Fig. 79), and the latter was sufficiently consolidated,

FIG. 79.



on the sleeper being subjected to a vertical load a wedge (prism) of ballast would be immovably held together by the flanges; the point of the wedge formed the angle 2α. According to the well-known theory of earth-pressure, $\alpha = \frac{\Pi}{4} - \frac{\mu}{2}$. The reaction on the surfaces of the wedge was R, forming with the normal the angle μ, and acting on the lower third of the surface. It was determined by the equation $p = 2\ R \cos \alpha$. Now if the wedge were to displace the earth on either side, a slip surface must result, the conjugated slip surfaces of which passed through the edges of the sleeper and produced the series of planes shown in Fig. 79. The resultant

Digitized by Google

cylindrical slip surface formed with this series of planes, which indicated the outer lines of pressure, the angle $2a$, so that the direction of pressure deviated by the angle μ from the normal to the slip surface. If the mass of earth thus bounded had the weight G, and its centre of gravity were at the distance g from the edge of the sleeper, then, as the outer lines of pressure exerted no leverage, the moment about the edge of the sleeper would be— Mr. Schwedler.

$$G\,g + R\frac{B}{3} \cdot \cos a - p\frac{B}{2} = 0,$$

whence $$p = \frac{2\,G\,g}{B} + \frac{2}{3}R\cos a = \frac{2\,G\,g}{B} + \frac{p}{3},$$

or $$p = \frac{3\,G\,g}{B}.$$

From an accurate drawing p could thus be directly ascertained. If the edge of the sleeper lay at a depth, h, under the surface of the ground, the layer above the cylinder of ballast to be displaced must be added to the weight G and G g become greater. The analytical calculation of the value of p derived hence gave—

$$p = \frac{B^2}{8}\gamma \cdot \frac{e^{3\rho a}}{\sin^3 a}\,\frac{e^{3\rho\frac{\Pi}{2}} + e^{-3\rho\frac{\Pi}{2}}}{3\rho + \frac{1}{3\rho}} + \frac{3\,B\,h\,\gamma}{8}\,\frac{e^{3\rho\left(\frac{\Pi}{2}+a\right)}}{\sin^2 a},$$

where the second portion represented the influence of the depth to which the sleeper was sunk in the ballast (e was the basis of the hyperbolic logarithm).

If the second part was ignored, and the material assumed to be sharp sand, which had an angle of repose of 3 to 4, then $\rho = \frac{3}{4}$, $\mu = 37°$, $a = 0{\cdot}46$ length of arc, $\sin a = 0{\cdot}4462$, and if $\gamma = 1{,}600$ kilograms per cubic metre (1·2 ton per cubic yard), or $\frac{1{,}600}{10^6}$ per cubic centimetre, then

$p = \frac{B^2\gamma}{8} \cdot 400 = B^2\,0{\cdot}08$, hence $\sigma = 0{\cdot}08$, the limit of displacement. With the coefficient of friction ρ of the material, the value of p altered considerably; thus—

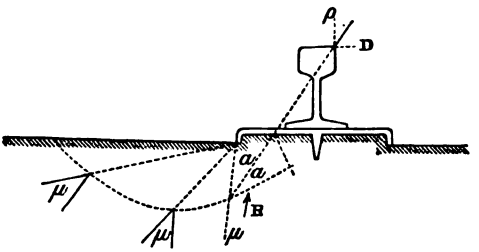
for $\mu = 30°, p = \frac{B^2\gamma}{8} \cdot 126;\ \sigma = 0{\cdot}025$
$\mu = 45°, p = \frac{B^2\gamma}{8} \cdot 1{,}800;\ \sigma = 0{\cdot}360$
} as the limit of displacement.

Digitized by Google

Mr. Schwedler. The roughness of the material used for ballast was consequently of great influence on the stability of the sleeper, on the one hand, and on the determination of dimensions on the other.

Besides, the pressure must act vertically and centrally on the sleeper. With an inclined pressure (Fig. 80) the wedge of earth, through the apex of which the line of pressure passed, and which was symmetrical to the latter, decreased rapidly, as did also the cylinder G, whereby displacement was greatly facilitated. The

Fig. 80.



object of tie-rods and transverse connections in the longitudinal sleeper was to resist the horizontal components of pressure, and the moment resulting therefrom, and of directing the pressure vertically and centrally with regard to the sleeper. In the transverse sleeper system this was effected by the rail and sleeper.

It only remained to speak of the individual supports. No doubt a round plate 50 centimetres in diameter, with a vertical rim turned downwards (flanged), was capable, if the ballast was sufficiently compressed, of sustaining a load of 5,000 kilograms (say 5 tons), and elastically transmitting it to the ground. Indeed, the running might be easier than with stone supports, as under the iron plate a small hollow would form in the middle, into which the centre, which alone should be loaded, sank gently. Instead of the smooth plate, one similar to that used for aneroid barometers would be not unsuitable. The plates would be laid horizontally, and furnished in the centre with inclined washers as supports for the rails. Now, although such plates might, on account of their considerable area, appear sufficiently rigid against side-pressure, still, for the purpose of maintaining the gauge and inclination of the rails, transverse connections of some stiffness could not be omitted. The thickness of the plates, which might be 0·2 inch or less, could not at present be theoretically determined; it was, however, important that they should retain a certain degree of elasticity. A similar

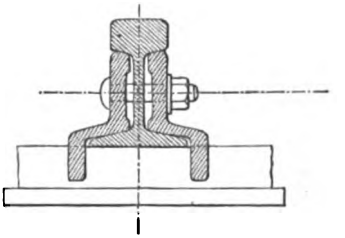
Digitized by Google

tendency appeared in the compressed transverse sleepers exhibited at the Paris Exhibition of 1878; these were narrow between the rails, wide outside the latter, and dished with a flange all round. Mr. Schwedler.

The reaction of the ballast was not uniformly distributed over the width of a sleeper or plate, but was smallest at the edges, and increased towards the middle proportionally to the distance from the edge. The plate only opposed the minimum of resistance during the manipulation in laying and ballasting; the bending moment was nil at the edge and increased towards the middle, as, for instance, in a plate supported at the centre and loaded pyramidally with earth. Where, in the case of longitudinal sleepers, their moment of inertia was of no importance, they might also be considered as a series of individual supports; or as a series of cross sleepers, specially arranged under each rail, which had, therefore, a width of 0·4 inch, and length of 11·81 inches, and were loaded in the middle. The calculation of the thickness was obtained by substituting, in the formulæ for the transverse sleepers, $2b = 0$ and $2P = p$ (p to be taken from the longitudinal sleeper). The thickness must then be taken as uniform, so that the moment of inertia remained constant. Following up this method a step further, a strip of corrugated plate iron, $11\frac{3}{4}$ inches or more wide, might serve as a longitudinal sleeper, in which every corrugation would be regarded as a small transverse sleeper for a single rail. The necessary rim of the longitudinal sleeper thus formed might, perhaps, be made by pressing down the corrugations during manufacture.

The rails for the transverse sleeper system of permanent way should, in the first place, have good fish-plates to replace the moment of inertia of the rail, as in the longitudinal system. It would be advisable to recess the fish-plates at the ends, so that they might rest on two cross sleepers and lay firmly between the latter to prevent the rails shifting (Fig. 81). Suppose the load P, from a wheel bore on the centre between two sleepers, the interval of the latter being λ, then the bending moment under the wheel, would be, with regard to the elasticity of the sleepers, nearly equal to that to which a length, λ of rail, freely supported at the ends, would be subjected, or $M = \frac{P\lambda}{4}$, as the advantage of continuity was partly neutralised by the elasticity consequent on soft ground.

Fig. 81.



Digitized by Google

Mr. Schwedler. On hard ground, M_o approximated to the value $\frac{P\lambda}{4} \cdot \frac{37}{53} = P\lambda\, 0{\cdot}173$, the strain on the rail being diminished. If the rail for longitudinal sleepers $\frac{I}{e}$ was compared with that for transverse sleepers $\frac{I_1}{e_1}$, with the same load P and the same stress K, there followed,

$$K = \frac{P e}{4 I} \sqrt[4]{\frac{4EI}{CB}} = \frac{P e_1 \lambda}{I_1 4},$$

$$\frac{I_1}{e_1} = \lambda \frac{I}{e} \sqrt[4]{\frac{CB}{4EI}},$$

$$I = 700,\ e = 5{\cdot}7,\ C = 3,\ B = 32;\ \sqrt[4]{\frac{CB}{4EI}} = \frac{1}{88},$$

$$\frac{I_1}{e_1} = \frac{\lambda}{88} \frac{I}{e}.$$

i.e. when the distance between the sleepers was 88 centimetres, (34·65 inches) both rails would have the same moment of resistance; with a greater distance the moment of resistance of the cross-sleeper rail must be correspondingly larger.

With regard to economy, the centre of gravity of the rail when worn out must be at half the height of the section of the rail. This also formed the basis of the calculation.

A width of head of $2\frac{5}{16}$ inches should, with respect to the wear caused by the wheels, be the minimum; to resist breakage the depth of head should be at least 1 inch; the web to resist inclined pressure say $\frac{3}{8}$ to $\frac{7}{16}$ inch; the flanges $3\frac{1}{2}$ to $3\frac{5}{8}$ inches wide, with a depth of $1\frac{1}{16}$ inch for longitudinal sleepers, and 4 to $4\frac{1}{8}$ inches wide, with a depth of $\frac{3}{4}$ inch for iron and wooden transverse sleepers. With reference to the fish-plate bolts, and the friction of the fish-plates, the surface of contact of the latter with the head and flange should have an inclination of 1:4. The depths of head and flanges were measured from the point of insertion of these inclinations. The depth of web was determined by the required moment of inertia. According to the amount of traffic a packing plate of from $\frac{3}{8}$ to $\frac{3}{4}$ inch should be added for the whole 9 metres' (29 feet 6·34 inches) length of the rail when soft homogeneous steel was used. From the above there resulted, for rails with longitudinal sleepers, a height of about 4·32 inches, and for rails with transverse sleepers a height of 4·72 inches, when worn out.

Mr. Smythe. Mr. A. J. Hamilton Smythe observed that, in discussing the practical value of the various systems of metallic permanent way,

Digitized by Google

it might fairly be premised that no system was likely to be generally used that required a special section of rail. Steel rails had been laid so extensively within the last few years, and their probable duration on the lines of moderate traffic, which composed the majority of railways, was so long, that it was hardly to be expected that they would be replaced by rails of other sections as necessary parts of any systems of metallic permanent way, however good. Mr. Smythe.

Much the same line of argument, so often used in discussing the relative advantages of transverse and longitudinal systems of wooden sleepers, appeared to apply to the case of metallic sleepers, and seemed to have led to the same result. The Author's statement that there could be no tendency in sleepers to shift endways on straight lines or easy curves was contradicted by experience. Where the ground was soft, or the ballast scanty, even straight roads laid with a heavy rail on wooden sleepers were frequently getting out of line, notwithstanding the greater friction of wood than of iron on ballast. Judging from this experience there seemed good reason for the Continental practice of closing the ends of the iron sleepers to increase the resistance to endways shifting.

The Author also doubted the advantage of burying the sleepers in the ballast; but considering the inferior bond formed between iron and ballast as compared with wood and ballast, it seemed all the more important for obtaining a steady road that iron sleepers should be well embedded in the ballast, and that in order to obtain a noiseless road as much ballast as possible should be laid over them.

Notwithstanding the quoted objection of Mr. Grüttefien to the horizontal feet of the Vautherin sleeper, they appeared to have the advantage of enabling a considerable weight of ballast to be imposed on the sleeper, and also to resist its tendency to rock on its longitudinal axis, which was found troublesome even with rectangular wooden sleepers, on account of the consequent displacement of the packing. The system of fastening devised by the Author appeared to be the simplest yet introduced as regarded laying in and removing the rails, but the bowed clip underneath the sleeper must interfere with firm and even packing at the point where this was essential. As regarded curving the transverse sleepers to obtain the tilt, it was obvious that straight sleepers were handier to stack and transport; but apart from this it was difficult to believe that curved sleepers could be depended on to keep the tilt and gauge true under heavy traffic, unless the packing were abso-

Digitized by Google

Mr. Smythe. lutely perfect. No doubt the use of tilt plates added to the probability of the road chattering; but if used wider than the rail base they would have a counterbalancing advantage in distributing the pressure of the rail over a greater area of the sleeper, thus preserving the surface of the latter to a considerable extent.

Mr. Vautherin. Mr. J. VAUTHERIN explained that the non-success of the Belgian trials in 1868 was due, firstly, to the insufficient thickness of the metal (the sleepers only weighed 12·5 to 13 kilograms per lineal metre, say 25 to 26 lbs. per yard), and, secondly, to the sleepers having been too short. The engineer of the Belgian Grand Central Railway thought it practicable to reduce the length of the intermediate sleepers to 86½ inches, and even to 82½ inches; so that the track took a series of double wave-lines in plan. Calling *a* the joint sleeper of 2·4 metres (94½ inches), the order was *a*, *b*, *c*, *c*, *b*, *a*, *b* and *c* representing lengths of 86½ and 82½ inches respectively. It was the short intermediate sleepers that broke. The justice of this conclusion was proved by the fact that in 200 kilometres of iron-sleeper track laid by the Belgian State Railways fractures had not occurred, and the same applied to the Dutch and German sleepers. The Author had not mentioned the employment since 1868 of the Vautherin sleepers, on 100 kilometres of the Algerian lines of the Paris and Lyons Railway. Mr. Demoly, the engineer of that company, had attentively studied the question of iron sleepers, and made a very interesting report on it. (See p. 70) This report, dated 9th July, 1880, was followed, on the part of its Author, by the ingenious and efficient modifications of the original fastenings, as described elsewhere. Mr. Vautherin's most recent English patent was not yet issued, but he submitted the German specification, and also drawings of the fastenings. He would add that the section adopted by the Bergisch-Märkisch Railway (Fig. 20) had his entire approbation, and was, indeed, adopted by himself in his first patent as an alternative, especially intended for use with coarse ballast. In conclusion he believed that the use of iron sleepers would have been sooner popularised outside Germany if it had not been at first endeavoured to produce them at a price as low as that of wooden sleepers, which had obliged the use of sections too slight for their work.

Mr. Wright. Mr. ROBERT WRIGHT had adopted the sleeper referred to by the Author (Fig. 22) in 1878, and there were now about fifty-five thousand of these sleepers in use in the main lines; and tenders had been issued for twenty thousand more. These sleepers answered very satisfactorily; there was no sign, or hearing, of chattering of parts, nor did he expect such, the clips and bolts

Digitized by Google

holding all firmly together. The tilt, or sole-plate, allowed the sleeper to lay so much the deeper in the ballast; and this was of much importance in Holland, where, in a great measure, hill sand had to be used for ballast. Curved sleepers, with their ends projecting upwards and exposed in summer to expansion from heat, followed by loosening of the ballast, and the middle of the sleeper taking a bearing on the ballast, and thus causing a rocking in the length of the sleeper, were, he thought, not to be compared with the advantages afforded by straight sleepers. The inspectors and gangers on the Dutch Rhenish Railway were in every way pleased with the sleepers, and found that a firm road was obtained after about twice good packing. He considered that the sole-plate gave strength to the sleeper where it was most required, and that it prevented the rail from wearing into the sleeper. The "Organ für die Fortschritte des Eisenbahnwesens," "Verein Deutscher Eisenbahn Verwaltungen,"[1] contained an article on the subject of curved sleepers, in which the writer, for various reasons condemned their use. In the same periodical it was stated,[2] that according to the experience obtained on the Rheinische railway in Prussia, the cost of labour in maintenance of the iron and steel permanent way compared very favourably with the old wooden-sleeper system. In regard to the longitudinal systems, since 1869 several hundred yards of Hilf's had been in use under his charge in the main line, subject to a moderately heavy traffic. It was the cheapest for maintenance, in regard to materials, of any road of which he knew; but it had the drawback that it continually crept in the same direction as the train, and thus gave extra labour in bringing back again from time to time. Haarmann's longitudinal system had been adopted for the steam tramway from the Hague to Scheveningen, and it made a first-rate smooth tram-road. He was inclined to think that Mr. Webb's sleeper would prove very suitable.

Mr. Wright.

---

15 November, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

The discussion upon Mr. Wood's Paper on "Iron Permanent Way" occupied the whole evening.

---

[1] 1881, pp. 137, 139. [2] 1881, p. 205.

Digitized by Google

22 November, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

(*Paper No. 1828.*)

"Forces and Strains of Recoil Considered with Referen to the Elastic Field Gun-Carriage."

By HENRY JOSEPH BUTTER, M. Inst. C.E.

IN order that gun-carriages may possess the requisite degree strength to enable them to withstand successfully the force of reco it is essential, in the existing mode of construction, that they shou have considerable weight: this in a field carriage is especiall objectionable, since excessive weight not only detracts from th mobility of the carriage in travelling, but, by opposing greate inertia in recoil, increases relatively the strain it has to bear. I becomes a question, therefore, of great importance to reduce th weight of such carriages to a minimum. To effect this, the design must be based upon as correct an appreciation of the action and extent of the force of recoil, under varying conditions, as can possibly be arrived at.

The "Researches on Explosives," by Captain Noble and Professor Abel in the "Philosophical Transactions of the Royal Society,"[1] have settled all questions relating to the action of the powder-pressure upon the projectile, with a completeness that leaves nothing to be desired. Unfortunately it did not fall within their province to ascertain from experiment the conditions of recoil, or indeed the mode in which it is generated. An opportunity which may never again occur—considering the skill, time and money expended upon the numerous experiments—was thus lost; and the subject remains, for all practical purposes, uninvestigated.

Certain simple formulæ are set forth in various books, and unproven statements are asserted by gunnery authorities, in re-

[1] *Vide* vol. clxv., 1875, p. 49.

Digitized by Google

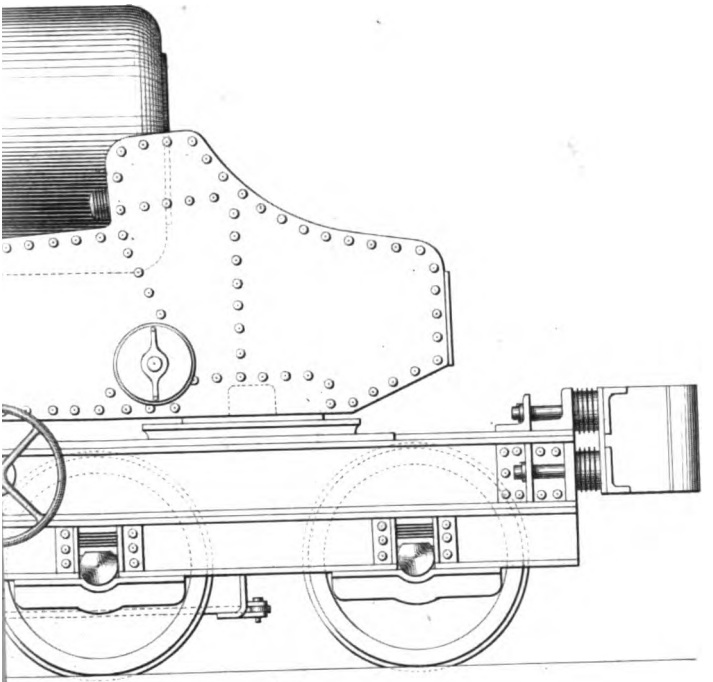
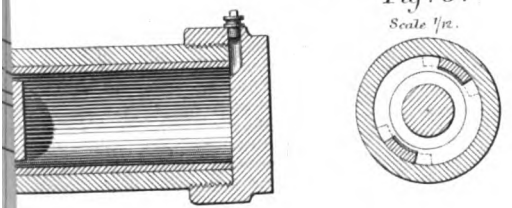
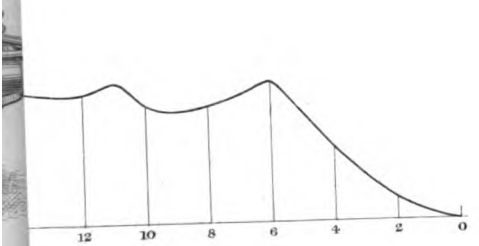


Fig : 5.

Scale 1/12.



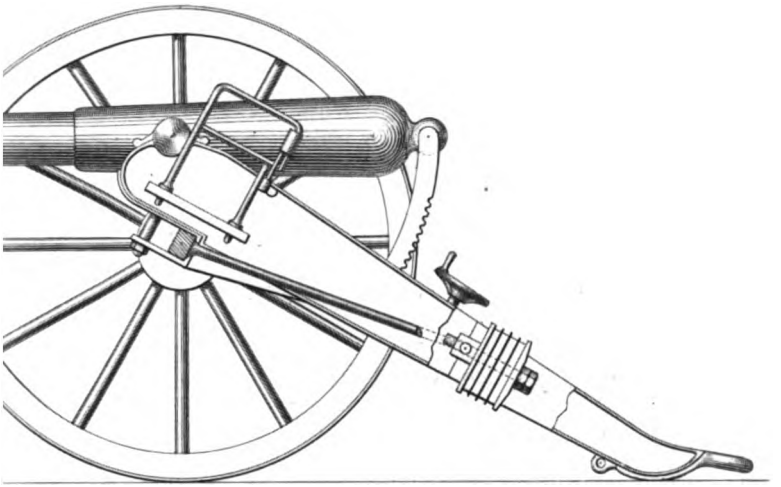


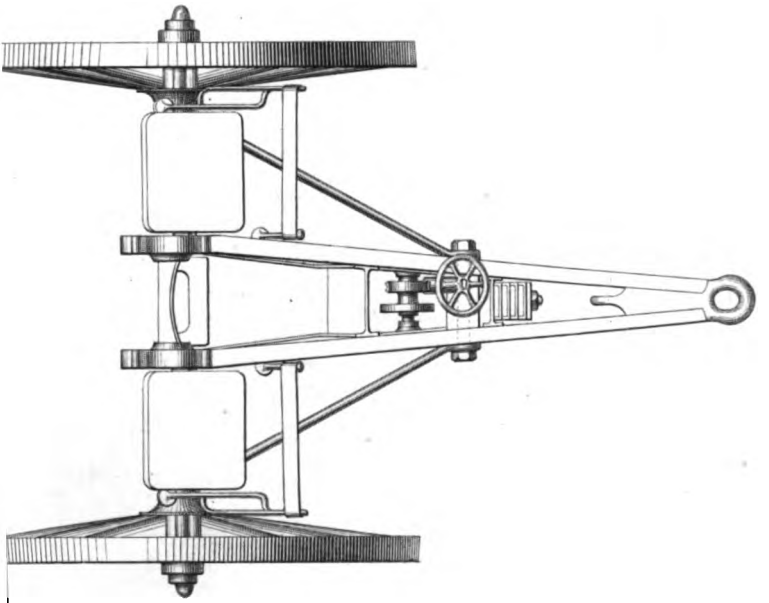
THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN.

Digitized by Google

Digitized by Google

Fig: 10.



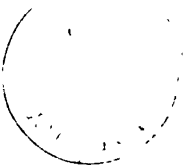


THOS KELL & SON, LITH 4C KING ST COVENT GARDEN

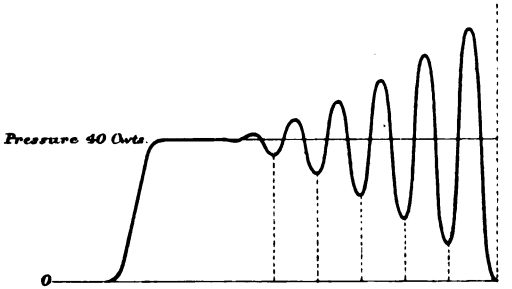
Digitized by Google

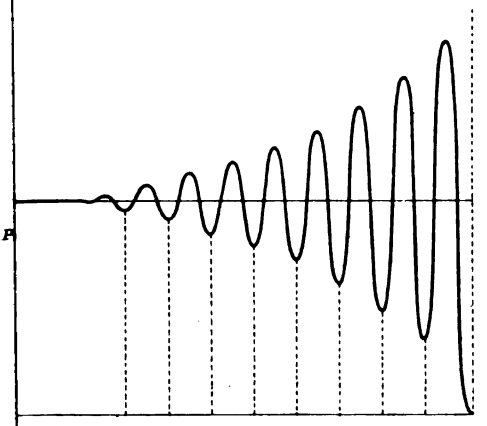
FORCE

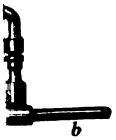
IN A

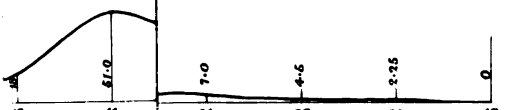


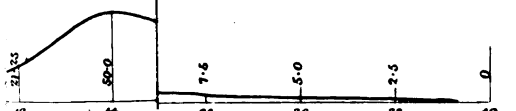
Digitized by Google

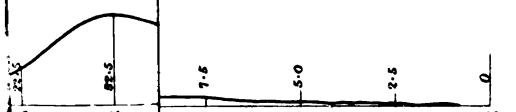








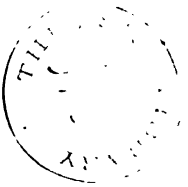




engths of Recoil

Digitized by Google

THOS KELL & SON LITH 40 KING ST COVE



Digitized by Google

ference to recoil, and these have hitherto been accepted without question; but a few isolated experiments and some observations extending over several years have been made, which throw considerable doubt upon their strict accuracy. The object of this Paper is to bring forward these facts and observations for what they are worth, and to endeavour to deduce from them the true nature and conditions of recoil; at the same time it must be confessed that the limited character of the experiments renders it impossible at present to arrive at anything more than an approximation to the exact laws.

The action of the powder-pressure has been considered, so far as recoil is concerned, as generating between the shot and the gun a force which causes the two bodies to recede from each other in the nature of reaction after impact. This gave rise to the adoption of the simple formula of the equality of momenta after impact, for ascertaining the velocity of recoil. Taking V and W to represent the highest velocity and weight of the gun, and v and w those of the shot,[1] then,

$$V.W = v.w$$

$$\text{and } V = \frac{v.w}{W}.$$

Hitherto this formula has alone been relied upon for ascertaining the velocity of recoil, scarcely any attention having been directed to find from experiment its true value under the varying conditions which now obtain in gunnery, although perfect means exist for doing so. Again it is stated that the force of recoil cannot exceed the maximum powder-pressure on the bottom of the bore, even in the case of holding the gun rigidly immovable. It is also thought by many that, while the slow-burning powders may increase the length of recoil, the intensity is less in the same proportion as the powder-pressure inside the bore.

It is difficult to understand how all these views can be held to be true by eminent authorities, since they depend upon directly opposite conceptions of the nature of recoil, unless upon the supposition that the question is regarded by them as of too small importance to seriously engage their attention; and this supposition renders the task of traversing these views one of less presumption than it would otherwise be.

There is little doubt that the above method of finding the velocity of recoil was sufficiently accurate in its results for S. B. guns, and

[1] It is usual to add to the weight of the shot one half that of the powder-charge.—H. J. B.

Digitized by Google

in a lesser degree for rifled ordnance firing R. L. G. powder. That it is not so under the conditions of employing very long guns using pebble powder, will, it is hoped, be demonstrated by some observations and the results of a few experiments now to be adduced, as a preliminary to the question of designing the most suitable carriage for field service.

When a powder charge is exploded in the chamber of a gun, a variable pressure is set up which acts equally, and in opposite directions, upon the shot and the gun; and this pressure acts for a definite and ascertainable period of time. The first effect of the pressure upon the shot is to compress the material at the base, and ultimately to overcome its inertia. If the pressure requisite to overcome its inertia exceeds the limit of elasticity, the shot becomes permanently set up, and may be so enlarged as to act as a plug and endanger the safety of the gun. This permanent enlargement has been frequently noticed in using shot made of soft cast iron. A certain interval of time is requisite in which to overcome the inertia of the projectile; hence when the powder, such as R. L. G., very rapidly burns, it produces such a quantity of gas that the powder-pressure nearly reaches its maximum before motion is set up, and the compression of the shot and consequent absorption of energy in overcoming its inertia are proportionally great. On the other hand, if a slow-burning powder be used, more time is permitted in which to overcome inertia, the powder-pressure is considerably below its maximum when the shot moves, and the compression of the latter is much less.

After motion has been set up, the powder-pressure continues to act as an accelerating force, rapidly increasing the velocity of the shot. The restitution, by means of its elasticity, of the material of the projectile to its original form, also reacts against the powder-pressure to accelerate velocity; and as there is ample time in which the restitution may be completed before the shot leaves the bore, it follows that the whole of the powder-pressure is utilised in imparting velocity to it.

From data furnished by the "Researches on Explosives" before alluded to, the curves represented in Fig. 1 have been drawn to show the pressures and times due to the discharge of a 10-inch gun with R. L. G. and pebble powders, acting upon the same weight of projectile. In the case of R. L. G. powder the maximum pressure, 21·84 tons, was reached in 0·00009 of a second; that of pebble, 18·02 tons, in 0·00043 of a second, or in an interval of time nearly five times greater. The total times of recoil were respectively 0·00085 and 0·00112 of a second, while the times occupied in

Digitized by Google

just producing motion in the projectiles, the base of each having advanced ¼ inch, were respectively 0·00005 and 0·00018 of a second. Therefore, as considerably more time in each case was permitted for the restitution than was occupied in the compression of the projectiles, and as the powder-pressure, so far as maintaining this compression, had practically ceased at the muzzle, it is evident that all the energy consumed in compressing the shot, while overcoming its inertia, acted ultimately to accelerate its velocity; and this is true of all guns in which the pressure at the muzzle is comparatively small, and is equally true of quick and slow-burning powders.

From the foregoing it may then be fairly accepted that the energy possessed by the shot at the moment of leaving the muzzle is derived from the powder-pressure in two actions, the one being of the nature of completed pressure of impact, and the other, and by far the larger, a directly accelerating force.

Turning now to the gun, it may be observed in the first place that the shot has left, or is on the point of leaving, the muzzle when recoil begins. From results obtained by instantaneous photography some years ago, in connection with the firing of a 25-ton gun using R. L. G. powder, it was shown that the shot was just clear of the muzzle before the gun moved. More recently it was ascertained by electricity that, in the case of the 6-inch B. L. gun using pebble powder, the shot was within about 2 inches of quitting the muzzle when the first movement of the gun occurred. The practical results of gunnery also demonstrate the general truth of these facts; for in several descriptions of carriages, the elevation of the gun is altered the moment the carriage begins to recoil, and if the shot remained in the bore after recoil commenced, the accuracy of fire would be affected to an extent which is not found to be the case.

It may then be considered certain that while the powder-pressure has completed its work upon the comparatively light shot, it has only had time to commence its action throughout the far greater mass of the gun, and the energy of recoil would appear to be due to the sudden liberation of stored-up work, rather than to the direct action of powder-pressure, since the latter has ceased before motion in the gun is set up.

Taking up once more the case of the 10-inch gun, it is found that the gun is one hundred and thirty-four times heavier than the shot, and although the powder-pressure acts precisely in the same way upon the shot and the bottom of the bore, it has to operate upon masses which bear the proportion of 1 to 134.

Digitized by Google

Time being such an essential element in overcoming inertia, it is not surprising that the pressure should act upon the inertia of the shot in the first instance, and afterwards perform upon it the function of an accelerating force, while during the same period it can only complete the wave of pressure in a mass one hundred and thirty-four times greater. This wave of pressure exhausts its action upon the elasticity of the mass of the gun, inducing a high degree of tension longitudinally; and, as the powder-pressure has practically ceased before the elasticity begins to react, since the inertia is barely overcome, it follows that the reaction of elasticity takes place in the absence of any opposing gas pressure, and in this respect resembles the pressure of impact of an inelastic body.

Recoil then is due to a purely dynamic force, the resultant of the sum of all the powder-pressures; while the energy possessed by the shot is derived from the same action in a more complete form, added to an accelerating force extended over a comparatively long interval of time.

The equality of momenta can only be true where the force of impact alone is concerned in producing the results, and therefore cannot apply to the motions of the gun and its projectile, as derived from the powder-pressure, which acts so variously upon them. Nor can the greater pressure of recoil under any circumstances be compared with the maximum powder-pressure, since it is the result of all the powder-pressures combined. It is equally impossible to conceive how it can be maintained that the action of recoil follows the variation of powder-pressures, being of high intensity and of short duration with quick-burning, and of lower intensity more prolonged with slow-burning powders, inasmuch as the gun is not directly obedient in its motion of recoil to the variations of powder-pressure, but stores up the total work of the pressures to be afterwards developed in one complete dynamic effort.

Before endeavouring to indicate the law which would appear to govern the force of recoil, it will be well to draw attention to certain facts and experiments bearing directly upon the question.

When charges of pebble powder were substituted for those of R. L. G., it was at once observed that the recoil of the guns was longer, notwithstanding that the muzzle velocities of the projectiles were practically unchanged. Frictional compressors were found unable to control properly the force of recoil, and hydraulic buffers had to be readjusted to suit the altered conditions. The hydraulic buffer is so perfectly uniform in its action that it can be accepted as a reliable measure of the force of recoil; its

Digitized by Google

resistance depends upon the ratio of the area of the piston to that of the orifice through which the fluid is permitted to flow; and it is found that the resistances vary inversely as the areas of such orifices, all other conditions being the same. When the adoption of slow-burning powder was found to increase the recoil, the areas of the orifices were reduced to increase the resistance, and this reduction was found to be invariably in the ratio of 4 to 3 to maintain the same lengths of recoil. It is therefore evident that the pressure of recoil had increased in the ratio of 3 to 4 with the use of pebble powder, notwithstanding that the total work of the powder-pressure was the same as with R. L. G. powder.

In Fig. 2 are represented time-curves of recoil taken during the discharge of a 10-inch gun with pebble and R. L. G. powders, giving in each case nearly the same velocities to the projectiles, those from pebble powder being, however, somewhat lower. All the conditions were identical except the change in the powder-charges. These curves were recorded by a pencil fixed to the carriage, and having its point resting upon a cylinder which made one revolution per second. They may not be regarded, perhaps, as giving absolutely correct results, owing to slight defects in the apparatus, but that they are sufficiently true may be seen from the parallelism of the curves taken under the same conditions. The difference in the direction of the R. L. G. curve indicates at a glance its low velocity as compared with that obtained from pebble powder. Similar results were found from a 25-ton gun.

In both cases the force of recoil as developed with R. L. G. powder was absorbed by the hydraulic buffer before the carriage reached the limit of recoil allowed in the platform; with pebble powder, however, the carriage was suddenly brought to rest by striking the stops, showing that there remained an increment of unexpended force after the resistance of the buffer had ceased.

The velocities of recoil may be estimated from the curves, the highest velocity being indicated after the gun had moved from 6 to 12 inches, and these velocities being squared, give the proportion existing between the pressures of recoil. Since the pressures set up in the hydraulic compressor vary as the squares of the velocities of recoil, they are per second—

		Velocity.	Square of Velocity.
25-ton gun	R. L. G. powder	13·15 feet	172·92
	Pebble „	15·38 „	236·54
10-inch gun	R. L. G. „	14·30 „	204·49
	Pebble „	16·70 „	278·89

The ratio of the squares of the velocities for R. L. G. and pebble

Digitized by Google

powder in each case is very nearly 3 to 4, and corresponds, as it should, with the ratio of resistances given by the hydraulic buffers. These facts show that while in certain guns pebble and R. L. G. charges may be used to give the same total powder-pressures, imparting to the projectiles equal energy, the slow-burning powder gives to the gun a force of recoil one-third greater than that resulting from R. L. G. powder.

There are only two conditions of variation in the action upon the gun of the powder-pressure to account for this, namely the difference in the maxima, and the duration of the total action. The difference in the force of recoil cannot be attributed to the first of these, as it has been shown that recoil does not depend upon the pressure at any particular moment, but upon the sum of all the pressures; and even if it did, the recoil from pebble powder should be less since its maximum pressure is less, whereas it is found to be greater. This is an additional proof of the error of referring the force of recoil to any particular pressure. It must therefore arise from the duration of the powder-pressure; and using once more the results of the "Researches on Explosives," it is found in the case of the 10-inch gun, that, while the required work was performed in the bore by R. L. G. powder in 0·00085 of a second, pebble powder occupied 112 of the same intervals of time to develop an equal amount of work in the projectile. These intervals of time are very nearly in the proportion of 3 to 4; and, taken in conjunction with the ratios already found to exist in the forces of recoil and the resistances of the hydraulic buffer, indicate the direction of the law governing the action of the powder-pressure upon recoil.

Thus, from separate observations on the squares of the velocities of recoil—the resistances offered by the hydraulic compressor to recoil, and the duration of the powder-pressures on the gun—the value of the ratio between the actions of quick-burning (R. L. G.) and slow-burning powders is found to be as 3 to 4.

The variation, therefore, in the force of recoil would appear to depend upon the product of the total powder-pressures and the intervals of time during which they act, so far as concerns guns which do not greatly differ from those alluded to, and in which the recoil commences at about the moment the shot leaves the muzzle. Assuming, as is found to be the case, that with R. L. G. powder the velocity of recoil can be sufficiently determined by the principle of the equality of momenta, and that by means of the velocity thus obtained the work of recoil can be estimated by the formula $\frac{V^2.W}{g}$

Digitized by Google

then in the case of most existing guns using pebble powder, the work of recoil may be found by the product of this formula with the ratio $\frac{4}{3}$, namely $\frac{V^2 . W}{2g} . \frac{4}{3}$, and the highest velocity of recoil by the formula $V = \frac{v w}{W} \sqrt{\frac{4}{3}}$

No doubt the tendency to reduce the maximum powder-pressure and to elongate the guns will eventually lead to low pressures acting in such great lengths of bores, the time of the powder-action being greatly prolonged, that these approximate formulæ will be found inadequate; and a series of carefully-conducted experiments will be necessary to determine the exact law under all conditions.

For example, it is quite possible to conceive the combustion of the powder being made so gradually progressive as to produce a uniform pressure in a gun resembling an enormously long pipe of comparatively small weight. The time of powder-action would in such a case be so greatly prolonged as to cause the pressure to act upon the gun in a similar manner to what it now does upon the shot, completing the pressure of impact and continuing to act as an accelerating force. In this instance the work of recoil would equal the energy given to the shot, instead of being, as now, only about one-hundredth part.

Thus, if the two extreme limits be taken, the force of recoil of short guns, using R. L. G. powder, may be ascertained from the equality of momenta, and that of sufficiently long guns, using powder which would give uniform pressures, from the equality of total energies. At present the truth lies between these two, and is much nearer the former than the latter, and may be taken to be sufficiently accurately expressed by the corrected formulæ given.

In future field-guns the greatly increased velocity imparted to the projectiles, added to the effect of using pebble powder, will result in an enormous increase to the force of recoil. In the case of the 9-pounder M. L. gun, using R. L. G. powder, the maximum velocity of recoil is 22·6 feet per second, calculated from the equality of momenta, and the work of recoil is 5,330 foot-lbs.; while in that of the proposed 12½-pounder B. L. gun they will be respectively 35·2 feet and 15,084 foot-lbs. But as pebble-powder will be used with the 12½-pounder, the work will be at least $15{,}084 \times \frac{4}{3} = 20{,}112$ foot-lbs., or about four times greater than that of the 9-pounder.

The weight of the 9-pounder carriage and limber is considered to be as great as it is practicable for a team of six horses to properly

Digitized by Google

manage in the arduous and rapid evolutions demanded of horse artillery; and as the 12½-pounder gun will be 1 cwt. heavier than the 9-pounder, it follows that the carriage and limber of the 12½-pounder must be 1 cwt. lighter than those of the 9-pounder in order that the combined mounting may be of the same weight. The 12½-pounder carriage must, therefore, be lighter than the 9-pounder carriage, while it is required to withstand four times the strain of recoil.

Obviously this problem can only be solved by designing such a carriage as will enable the strain of recoil to be gradually applied; by interposing, in fact, some elastic apparatus between the gun and the carriage proper, by which the inertia of the latter will be overcome in a longer interval of time, and consequently with less strain. This constitutes the principle of the so-called elastic field carriage, elastic in the sense of admitting a change of form and absorbing force thereby. The principle has been applied in the construction of a proof carriage for the 26-ton B. L. gun, and it will be well to consider this before taking up the question of the field carriage, especially as the proof carriage is in the nature of a field carriage, and bears about the same proportion of weight to the gun.

A side elevation of this carriage is represented in Fig. 3. It consists of a wrought-iron frame resting upon two bogie carriages. The gun is seated on blocks, which, on recoil, slide on the frame through a space of 3 feet; these blocks are bored out to form hydraulic cylinders, the piston-rods of which are securely attached to the frame. The diagram represents the gun in the firing position with the clear space of 3 feet behind the blocks; the piston of the hydraulic cylinder is at the rear end, and the whole of the fluid with which the cylinder is filled is in front of the piston. During recoil the piston must pass through a 3-feet column of fluid before the gun blocks can act directly upon the frame, except by friction and the resistance of the hydraulic compressor, to drive it backward. The fluid which it displaces in its progress passes through small orifices in the piston, in the same manner as in the ordinary hydraulic buffer of the service. Taper bars are used in the orifices to gradually contract their area during recoil, and thus to maintain an approximately uniform resistance throughout; while by rotating the rods at pleasure, and securing them in any required position before firing the gun, the areas of the orifices are enlarged or reduced to obtain a lesser or greater resistance. A longitudinal section of the buffer is shown in Fig. 4, and the adjustable piston in Fig. 5.

Digitized by Google

The hydraulic cylinders are connected by a pipe at their front ends to equalise the pressure set up; and a pressure-gauge registers, by means of a pencil fixed to the outer end of its plunger, upon a piece of paper fastened to a flat board secured to the frame, the variations of pressure per square inch occasioned by recoil, which pressures represent the resistance opposed by the fluid to the passage of the piston, and determine the velocities of flow through the orifices.

One of the diagrams of pressures thus obtained is represented in Fig. 6. The area of the orifices had been so regulated as to cause the pressure to cease, or in other words the gun to cease its effort to move the carriage, the moment the blocks had traversed 3 feet. It will be observed that the point of maximum pressure is situated at about 6 inches from the commencement of recoil, and as the pressures vary as the squares of the velocities of the gun's motion, the maximum velocity of recoil was reached at about this point.[1] This agrees with results obtained from other guns; thus the 38-ton gun would appear to attain its highest velocity after 8 inches of motion.

The effect of the powder-pressure stored up in the gun is to impart an increasing velocity, which reaches its maximum after the gun has been moved a certain distance; thus the wave of pressure set up in the gun by the powder-pressure overcomes the inertia, and continues by the reaction of elasticity to augment the velocity of the gun, until, in the case of the 26-ton gun, it has passed over 6 inches of space, at which point the normal condition of tension in the mass is restored. It must be borne in mind that the powder-pressure ceases just as inertia is overcome in the gun; therefore the gradually-increasing velocity is due to the tension and reaction of the elasticity as stated.

If there were no elastic medium between the gun and the carriage, the carriage would be similarly affected, as regards its motion, with the gun; and the pressure necessary to impart the highest velocity of recoil to the combined gun and carriage would act through nearly the same space of 6 inches; such maximum velocity being of course less in proportion to the greater weight acted upon.

This feature in recoil is exemplified in the case of using hydraulic

[1] The rise of the gauge due to increase of pressure must follow, and cannot precede, the increase in velocity, since the pressure is a direct consequence of the velocity: the highest point, therefore, of velocity may be, and most probably is, reached before that of the highest pressure as indicated by the gauge, and cannot therefore exceed 6 inches.—H. J. B.

Digitized by Google

cylinders filled with water, having no air space, and the piston rods acting in tension; for water being practically incompressible, and possessing considerable inertia, would offer so enormous a resistance to taking up immediately the highest velocity of flow, amounting in some cases to over 1,000 feet per second, that the destruction of some part of the apparatus would inevitably result. All the pressure diagrams, however, show that this highest velocity is reached gradually, and as the fluid pressure is the direct result of the velocity of the gun, therefore the highest point of pressure at once indicates the highest velocity of recoil.

By the introduction of the hydraulic buffer, or press, between the gun and the carriage, the pressure of recoil which acts through 6 inches in the case of a rigid carriage, is made to extend its action over 3 feet, and as the amount of work expended is the same in each case, it follows that the pressure upon the carriage in the latter case will be reduced to one-sixth of what it is in the former.

From an observation which was made independently of the pressure curves, it was ascertained that the carriage began to move when the gun had reached its maximum velocity, viz., after having recoiled 6 inches; from this point the pressure in the buffer fell, but continued high for some time, as the first movement of the carriage was slow. The velocity of the carriage continued to increase and the pressure to fall in a corresponding degree until the 3 feet of space were traversed by the gun, at which point the carriage had acquired the same velocity as the gun. All pressure in the buffer then ceased as the gun no longer moved faster than the carriage, and both the gun and carriage from this point moved backward as one mass.

The total work of the hydraulic buffers, shown by the areas of the pressure diagrams, together with the resistance due to friction and gravity, represent the expenditure of a portion of the accumulated work of recoil, and consequently of a reduction in the gun's velocity, thus:—

The maximum velocity of recoil of the gun (calculated)	= 20·8 feet per sec.
" " " gun and carriage rigidly connected	= 10·4 " "
Accumulated work of recoil of the gun	423,958 foot-lbs.
Work due to the total resistances of the buffers and of friction and gravity acting through 3 feet	288,960 "
Unexpended work in the gun when its pressure on the carriage ceased, and they moved together as one mass	134,998 "

and the velocity of the gun due to the remaining accumulated work of 134,998 foot-lbs. = 11·74 feet per second.

Digitized by Google

It will be seen from the foregoing that if the gun and carriage be rigidly connected, the gun will start off with an amount of accumulated work which will impart to the carriage a velocity of 10·4 feet per second, itself falling to the same velocity in 6 inches. With the elastic medium in action, the same will be effected in 36 inches, the velocity being 11·74 feet per second.

Allowing for errors of observation and in the data for calculation, these velocities agree sufficiently to show that for all practical purposes it may be assumed the same work is expended in giving the highest velocity to the carriage, whether it act through 6 inches or through 36 inches, the maximum pressure in each case being as follows :—

Mean pressure in hydraulic buffers through	3 feet	29 tons.
„ due to friction and gravity	3 „	14 „
Total		43

Corresponding mean pressure to produce the same aggregate work in 6 inches = 43 × 6 = 258 tons.

But in the latter case the maximum pressure will be about twice the mean pressure, the action corresponding with that of impact = 516 tons pressure; while in the former it is found to be 52·2 tons, or only one-tenth part of what it would have been without the elastic medium. The great importance of the adoption of this principle, especially in the construction of field carriages, is thus apparent, even when due allowance is made for errors resulting from the insufficient data available for exact calculation.

In order to ascertain the strains set up by any gun upon its carriage, the distance traversed by the gun before attaining its maximum velocity must be known, or estimated in some reliable manner. In the case of the 12½-pounder B. L. gun, this distance is at present unknown, and must therefore be estimated. The ratio between the powder-pressure on the bottom of the bore and the total weight of the gun, or the pressure per unit of weight, should afford the means of arriving approximately at this distance, since the rapidity with which a given mass is affected by various pressures depends upon the variation among the latter. Fortunately there are a few observations which sufficiently confirm the general correctness of this view.

In the 26-ton gun the maximum pressure on the bottom of the bore is about 1,350 tons, while the weight of the gun and carriage is 56·6 tons, therefore $\frac{1,350}{56·6}$ = 23·86 = pressure in tons per ton of

Digitized by Google

weight; and this gun moves over a space of 6 inches before attaining its highest velocity of recoil. It has been observed that the 38-ton gun and the 6-inch 4-ton gun move over spaces of about 8 inches and 2½ inches respectively, and these agree very nearly with the spaces when estimated from their pressures per unit of weight, taking the 26-ton gun as a standard of reference.

Calculated on this approximate method, the 12½-pounder gun mounted on a rigid carriage would attain its highest velocity of recoil after 1 inch of movement, or probably 1½ inch allowing for the far greater elasticity of field-carriages. Assuming then this space as being sufficiently accurate, a field carriage has to be designed to enable the pressure of recoil, which expends itself in 1½ inch of motion upon a rigid carriage, to be extended over, say, 9 inches.

Several conditions of construction in the rigid carriage (Fig. 7) may not be greatly altered in the elastic carriage, and giving due consideration to these, and applying the elastic apparatus in various ways, different designs were worked out, one of which only, as being sufficient for the purpose, is selected for illustration. In this design (Fig. 8), a tubular steel axle is adopted, which passes through the upper ends of a pair of levers constituting the trail; two upright levers are connected with and rotate about the axle; the gun rests in the upper ends of these levers, and is connected at the breech end to the piston-rod of a hydraulic buffer, the buffer itself being fastened to the axle.

The hydraulic buffer (Fig. 9), which constitutes the elastic medium, is made wholly of gun-metal to ensure regularity of action, and is small and light, weighing only about 28 lbs., which admits readily of spare buffers being carried with the battery, yet possessing ample strength to resist the pressure of recoil. The levers are so placed as to cause the centre of gravity of the gun, when in the firing position, to be 6 inches in front of a vertical line passing through the centre of the axle, to ensure the gun, after recoil, falling of itself into the proper position for firing. Stops with india-rubber pads are provided to receive the weight of the gun in the two extreme positions.

From the data furnished by the preceding investigation on the force of recoil, and the ascertained results of the same principle of carriage used with the 26-ton gun, a fair approximation may be made to the enormous reduction of strain gained by the use of the elastic principle in this carriage. The highest velocity of recoil of the gun is found to be 36·12 feet per second, while that of the gun and carriage rigidly connected is 15·56 feet per second. The accu-

Digitized by Google

mulated work given off by the gun in imparting to the carriage the latter velocity, calculated from these velocities, is 12,935 foot-lbs.[1]

This work is performed in $1\frac{1}{2}$ inch in the case of the rigid carriage, and in 9 inches in that of the elastic carriage. In the latter case this results in a mean pressure of 7·7 tons, and in the former of 46 tons; but inasmuch as the maximum pressure in the hydraulic buffer can be regulated to be $1\frac{1}{2}$ time the mean, or even less, and the maximum pressure of impact upon the rigid carriage is twice the mean, they will be respectively $11\frac{1}{2}$ and 92 tons. Thus, as nearly as can be estimated, a pressure of impact amounting to 92 tons has to be sustained by the rigid carriage, while the elastic carriage will only be required to meet one of $11\frac{1}{2}$ tons, and this more in the nature of a statical pressure.

No doubt the very limited experimental data at present available render the method adopted to arrive at these results only approximately true; but it is believed that fully sufficient allowance has been made for possible variations, especially in the direction of understating the reduction of strain to be sustained in the elastic field carriage, and at least fully justifies the construction of a carriage on this principle 1 cwt. lighter than the 9-pounder carriage, and fitted to stand at least four times the accumulated work of recoil.

---

[1] Muzzle velocity of shot = 1,703 feet per second.

Weight of { Gun = 784 lbs. / Shot = 12·5 „ / Charge = 2·75 „ } shot + ½ charge = 14·4 lbs.

„ „ carriage and gun = 1,820 lbs.

Highest velocity of gun $= \frac{14\cdot4 \times 1{,}703}{784} \times \sqrt{\frac{1}{3}} = 36\cdot12$ feet per second.

„ of gun and carriage $= \frac{14\cdot4 \times 1{,}703}{1{,}820} \times \sqrt{\frac{1}{3}} = 15\cdot56$ „ „

Accumulated work of recoil in gun, with 36·12 feet velocity $= \frac{36\cdot12^2 \times 784}{64\cdot4} =$ 15,882 foot-lbs.

Accumulated work of recoil in gun, with 15·56 feet velocity $= \frac{15\cdot56^2 \times 784}{64\cdot4} =$ 2,947 foot-lbs.

Work to be absorbed by hydraulic buffer in 9 inches ($\frac{3}{4}$ foot) = 15,882 − 2,947 = 12,935 foot-lbs.

Mean pressure in hydraulic buffer $= \frac{12{,}935}{\frac{3}{4}} = 17{,}247$ lbs. or 7·7 tons.

Mean pressure of impact acting through $1\frac{1}{2}$ inch $= \frac{12{,}935}{\frac{1\cdot5}{12}} = 46$ tons.

Digitized by Google

When a carriage travels at the rate of 12 miles an hour, the velocity is 17 feet per second, and when moving at this rate over broken and rocky ground, which is often the case with Horse Artillery, and sudden concussions are encountered, with the carriage in more unfavourable positions to meet them than when fired, it can well be conceived that travelling is often as severe upon the structure as firing, especially upon the wheels and axle. The elastic principle is therefore extremely valuable in this respect, and renders it desirable to apply it to the limber and wagon, in order to lessen the strains brought upon the frames and axles by the dead weight of the ammunition boxes.

These strains are mostly horizontal, and in order to meet them, the boxes are suspended as shown in Fig. 10, and are sustained in a normal position by light steel springs. A hydraulic buffer placed between these springs enables the dynamic effects of the sharpest concussions to be converted into more gradual strains; thus preserving the structure from destruction, and at the same time enabling its weight to be diminished, and rendering riding much easier for the gunners who are seated on the boxes.

The elastic principle may be said to exist already in the Engelhardt Russian field carriage, Fig. 11, but that is essentially different from the one just described. In the first place it is used only between the carriage and the axle, and thus affects only the axletree and wheels. It saves some weight in the latter, but necessitates the introduction of an equivalent weight in the apparatus, which renders the whole structure fully as heavy as it would be without the adoption of the principle. And lastly, the elastic medium of which it admits the use, india-rubber or steel springs, stores up the small portion of the pressure of recoil it is designed to meet, and redevelops it afterwards as the recoil continues; whereas the hydraulic buffer possesses no reaction.

In order to avoid any interruption in the proper sequence of the preceding arguments, it has been hitherto assumed that the pressure-curves of recoil accurately represent the energies of recoil, less the amount due to friction and gravity. A point of so much importance, however, cannot be expected to be received without careful demonstration; and as the proof involves the description of some facts connected with the action of pressure-gauges, which cannot fail to be of interest to Civil Engineers generally, since it is believed they have never been experimentally observed before, such proof will be given with somewhat greater minuteness than has been

Digitized by Google

possible with other points in this Paper, embracing as they do so wide a range of investigation.

In Fig. 12 are drawn three pressure-curves, taken during the recoils of the 43-ton B. L. gun, under similar conditions. It will be observed that from some cause the curves are not uniform in themselves, but indicate a wave-motion inconsistent with the continuous reduction in the velocity of recoil; and it is clear that the series of ordinates cannot accurately represent the successive pressures due to the squares of the decreasing velocities. But although each ordinate, taken separately, does not give the exact pressure at that point of the recoil where it is situated, yet the sum of the ordinates may accurately give the total resistance of the buffer, notwithstanding the wave-action.

In the first place it will be seen how uniformly the waves are repeated in the three curves, and the same is the case in a dozen or more curves taken at the same time, showing that they are produced by the action of some constant law, and their gradual reduction of amplitude and of length lead to the supposition that they are due to the vibrations of the spring of the pressure-gauge when acted upon by the sudden application of the pressure of recoil.

To determine this point, and at the same time to ascertain how nearly the area corresponded with the energy of recoil, a series of experiments was carried out with the apparatus shown in Fig. 13. This apparatus consists of an air and water vessel, *a*, into which water is forced by a pump, through the pipe *b*, to set up any required degree of pressure. The air with which it is charged before admitting the water becomes compressed into the upper part, with a degree of pressure equal to that exerted upon the water. A gauge *c* indicates the pressure per square inch inside the vessel, while the gauge *d*, used for registering the pressure of recoil, is connected to the vessel by a short pipe, and has its pencil resting upon a sheet of metal or of paper, and a valve, *e*, is used to cut off, or communicate, pressure to the recoil gauge.

Before carrying out any experiment, great care was taken to fill properly with water the two gauges, in order that the results should in no way be affected by the presence of any air accidentally enclosed in them.

The first experiment consisted in closing the valve *e*, and pumping up a pressure of 1 ton to the square inch. The valve was then suddenly opened and closed, to correspond with the mode of action of the pressure of recoil. The index of the gauge *c* remained perfectly steady at 1 ton, while the pencil of the recoil gauge

Digitized by Google

registered $1\frac{3}{4}$ ton. This was repeated with pressures of 2 and 3 tons, with similar results.

The adoption of various degrees of speed in opening the valve *e* showed that by completing the action as gradually as possible, the excess of pressure above that in the vessel might be reduced to about 25 per cent., and that it might be raised to 75 per cent. by performing it in 0·2 of a second.

These results appeared to prove the unreliability of the pressure-curves; but as the reaction of the spring seemed to carry the pencil much below the point of statical pressure in the vessel, a modification was made in the apparatus, by which it was hoped that some further information might be obtained regarding the value of the vibrations. This modification consisted in moving the plane while the pencil was recording the pressures, when it was seen (Fig. 14) that the sum of the areas of the waves above the line corresponding with the steady pressure was equal to that of those below the line.

The amplitude of the vibrations, taken as a whole, was bisected by the normal line of pressure, and the pencil indicated, by the reactions of the spring, as great a percentage below the line of statical pressures as by its actions it did above it. This being found to be true at all pressures, the fact was established that, no matter how much the spring of the gauge vibrated by the sudden application of the pressure, the area of the diagram as truly represented the total energy acting upon the spring as it would do if the pressure had been so gradually applied as to have produced a fair curve, free from all wave-actions.

Theoretically these wave-actions should be isochronous at all pressures. To test this, a regular and known rate of motion was imparted to the plane upon which the records were made, with the results shown in Fig. 14. From this it is seen that at various pressures, and with various degrees of suddenness in applying the pressure, the lengths of all the waves are precisely the same. This suggested the possibility of estimating from the recoil curves the velocity of recoil, as a further means of testing the value of the corrected formula, $V = \frac{v\ w}{W}\sqrt{\frac{4}{3}}$

To obtain reliable data, the identical spring and gauge used to find the recoil curves shown in Fig. 12 were employed in the apparatus, and a pressure applied which would give the same action to the spring as the maximum pressure indicated in the curve. The reduction of the pressure of recoil would not affect the time-value of the waves, as shown by the diagrams taken at

Digitized by Google

various pressures (Fig. 14), in all of which the lengths of the waves were the same. The result arrived at was, that the time occupied in completing each wave was 0·0506 of a second.

From this time-value of the waves in the recoil curves, the highest velocity was found to be 18·6 feet per second, while the velocity calculated from the formula $V = \frac{v\,w}{W}\sqrt{\frac{4}{3}}$ is 18·7 feet per second.

To test still further the value of the preceding results, and at the same time to include in the trial the question of the reliability of the areas of the recoil curves as representing the energies of recoil, it was considered desirable to attempt to find the highest velocity of recoil by another method, employing these areas as a means of doing so.

The total energy of recoil (U) is expended in overcoming friction (F), gravity (G), and the resistance (R) of the buffer, *i.e.* $U = F + G + R$, and putting V and W to represent respectively the highest velocity of recoil and the weight of the gun and its carriage, then the total energy of recoil is found by the well-known formula, $U = \frac{V^2 W}{2g}$, therefore—

$$R + G + F = \frac{V^2 W}{2g},$$

$$\text{and } V = \sqrt{\frac{(R + G + F)\,2g}{W}}.$$

The mean area of several of the recoil-curves indicated 607,600 foot-lbs., and the value of $F + G$ was 47,040 foot-lbs., giving as the total value of U, 654,640 foot-lbs.; therefore—

$$V = \sqrt{\frac{654{,}640 \times 64{\cdot}4}{114{,}240}} = 19 \text{ feet per second.}$$

These three wholly independent methods of calculating the highest velocity of recoil, then, stand thus, as respects their application to the 43-ton B. L. gun—

From the corrected formula	18·7	feet per second.
From the time waves of the curves . .	18·6	„ „
From the areas of the curves . . .	19·0	„ „
Mean	18·8	„ „

Showing a variation in each from the mean of only 0·2 foot. So remarkable a degree of identity, following the important results obtained in the experiments with the apparatus, Fig. 13, may

Digitized by Google

fairly be accepted as demonstrating that the undulations of the curves of recoil are due to no accidental disturbing cause, as held by many persons, but that they are the result of a well-defined law; further, that the total area of the diagram correctly represents the total energy of recoil absorbed by the buffer; and lastly, that the waves being isochronous afford the means of estimating the highest velocity of the recoil.

It may be mentioned incidentally that the highest velocity of recoil, as calculated by the method now in general use, $V = \frac{v\,w}{W}$, for the 43-ton B. L. gun is 16·2 feet per second, giving for the value of the total energy of recoil 465,550 foot-lbs., which is little more than two-thirds the correct value. Either of the three methods now brought forward may be used to find the velocity of recoil, but the one which will be found to be the most readily available is the corrected formula $V = \frac{v\,w}{W}\sqrt{\frac{4}{3}}$, the other two being merely regarded as valuable proofs of its general correctness.

In conclusion, it will be well to summarise the results arrived at in the preceding investigations, which, although differing widely from the opinions generally held, and from their novelty likely to be regarded, for a time at least, as doubtful, are, it is believed, so completely demonstrated to be true by the many diverse facts and considerations brought forward, as will ensure their ultimate acceptance by the profession generally; at any rate, until occasion is afforded to correct them by more extensive observations and experiments than are at present available.

First, with reference to the use of the pressure-gauge for recording diagrams of pressure. The vibrations due to a sudden application of pressure in no way affect the reliability of the calculation of the total energy from the area of the curve, provided the wave-action has ceased before the curve is completed; and further, the intervals of time during which the pressures act can be fairly estimated from the lengths of the waves. These results have been indicated to some extent in various theoretical considerations of the nature of wave-actions, and having now been experimentally demonstrated, will not only be found to be of value in the science of gunnery, but will be useful in many directions, not perhaps immediately obvious, but which may arise from time to time.

Secondly, the nature and action of recoil have been carefully considered with the aid of data universally accepted as true, and by the results of experiments of so varied a character as mutually

Digitized by Google

to prove their reliability. These observations establish the following facts:—

That the maximum pressure of recoil is independent of any particular pressure in the gun, being the resultant of all the pressures, and under certain circumstances may greatly exceed the maximum powder-pressure on the bottom of the bore.

That slow-burning powders, by acting more gradually in overcoming the inertia of the gun than quick-burning powders, induce a greater energy of recoil, in the proportion of the longer intervals of time during which they act upon the gun; and this notwithstanding that the energies imparted to the projectiles are the same.

Thirdly, that the present method of calculating the highest velocity of recoil solely by the principle of the equality of momenta would appear to be incorrect, and that in the case of the present type of gun, using pebble powder, the formula $V = \frac{v w}{W}\sqrt{\frac{4}{3}}$ may be accepted as giving sufficiently reliable results. Also, that the velocity may be estimated from the measurement of the waves occurring in the pressure-curves of recoil, or from the total energy of recoil as represented by the area of the complete diagram.

Fourthly, that the strains of recoil upon the gun-carriage may be reduced to nearly one-tenth in intensity by interposing a suitable elastic medium between the gun and the carriage, and thus delaying the action of overcoming the inertia of the latter, by which the weight of travelling carriages may be reduced to a minimum.

The Paper is illustrated by several diagrams, from which Plates 2, 3, and 4 have been prepared.

Digitized by Google

Discussion.

Mr. Butter. Mr. BUTTER remarked that if he had gone into matters of mere mechanical detail, the Paper might have been more interesting, but it would not have had the permanent value which he believed it now possessed. If during the discussion any errors in the deductions should be discovered, the Paper would still have served a good purpose in bringing the matter before the Institution, because there were various questions requiring investigation, to which no answer had yet been given, and which he trusted would receive due consideration and thorough criticism at the hands of the members. He had received various communications from gentlemen who were unable to be present; and in one of them there was a misconception, which he thought it right to remove, with reference to the value of the formula $V = \frac{v\,w}{W}$, the formula for finding the velocity of recoil from the equality of momenta. He had stated in the Paper that w represented the weight of the shot, and had incidentally remarked that it was usual to include in that weight half the weight of the charge. Some persons included the whole weight of the charge; and to avoid misconception he desired to state that, although he had only alluded to it as including the weight of the projectile, yet throughout the whole of the calculations it included half the charge as well. The writer of the letter had attributed the increase of velocity of recoil in the case of pebble powder to the fact, that a larger charge was used to get the same initial velocity of the projectile than with R. L. G. powder, and therefore w possessed a higher value when pebble powder was used than in the case of R. L. G. powder. That was no doubt the case to a certain extent; but he had gone over the matter to find out what was the extent to which it would affect the question, and he had ascertained that in the case of the 10-inch gun fired with a 300-lbs. projectile, and 60 lbs. of R. L. G. powder, and with 70 lbs. of pebble powder, the respective velocities of recoil were 14·3 and 14·5, whereas by the actual curves taken from the gun the velocities were 14·3 and 16·7; so that it would be seen that the addition of the weight of the charge to the formula did not in any material sense alter the result arrived at from the actually observed curves. The only alteration in the ratio was that, instead of being as 3 to 4, it was as 3 to 3·98. Neither half the charge nor the whole charge was sufficient to account for the large increase

Digitized by Google

in the velocity. It had been long suspected that the formula itself failed to give the true velocity with the change of powder, and in order to endeavour to increase the value, the whole weight of the charge (which was manifestly incorrect) had been taken, and a constant in addition. In some French publications it was stated that w should include the weight of the shot and charge, and also a certain constant; that constant he had found to be $\sqrt{\frac{2}{3}}$ from the considerations which had been set forth in the Paper. With regard to the use of the term "Elastic field gun-carriage," it was elastic only in the sense of admitting a change of form, and of absorbing force by that change of form. Of course when a spring was compressed in one direction it absorbed a certain amount of force; then it reacted and gave the force out again. The complete elastic action was a compression and a restitution; in the application of the elastic principle to the field carriage, it was only the first part of that action, the absorption of force, as in the case of a spring made of steel or india-rubber; the restitution was absent from it, and that was considered to be rather desirable than not. Mr. Butter.

Colonel SHAKESPEAR said the question of the recoil of guns should be regarded as a question of war, and not treated as if the guns were at Shoeburyness. Heavy guns recoiled up-hill on a platform, but field guns recoiled upon the bare ground, and most frequently down-hill. In regard to the former, he had no doubt that the Author was right, but he had hardly grasped the requirements of light field guns. He might be permitted to mention some incidents that had occurred in his own experience, which would show that the recoil of a field gun was a very immaterial point. Whereas a heavy gun was always on a known platform, the field gun was always on unknown ground, and generally on ground falling from the enemy. Sometimes the gun was placed on ground sloping towards the enemy, but rarely on the top of a hill where it was flat; and the recoil was much greater when the ground was declining towards the rear, and the reverse when towards the front, as then the trail was forced against the hill. A great deal also depended on the length of the trail. A horse artilleryman cared very little about the recoil of his gun, but he regarded the construction of the carriage as a material point. The late Field-Marshal Sir Hew Ross once told him a story about Norman Ramsey's Horse Artillery at Fuentes de Onoro which was practically captured. He formed his guns at close interval, and galloped through the enemy's cavalry, going over very rough ground; there was a great deal of bumping, but he got away, and no harm was done. He might also mention his own ex- Colonel Shakespear.

Digitized by Google

Colonel Shakespear.

perience at the battle of the Alma. After watching the Russian cavalry all the morning, and protecting the left flank of the English army; on seeing the Russian cavalry move off, the Artillery galloped down a slope of rough ground to cross the river, going at full pace. Just before getting to the river the near wheel of the left gun caught the angle of a wall. The gun went over, and the horses and men fell down; but they all got up again unharmed. He remembered that on an occasion at Aldershot one of the leading horses was ill, and another had been put in its place. It was a wagon horse, with upright shoulders and upright pastern. At the pace they were going that horse fell and the others rolled over him, and the gun fell on its side, but all got up again unhurt. These facts showed that the material was the great thing to be considered in the construction of a Horse Artillery gun-carriage, and that the question of recoil was of no importance in the field. No doubt some field gun-carriages might be improved, but they would have to go through the same kind of rough usage as before, for war was not likely to be quieter work in future than it had hitherto been. He had spoken of Horse Artillery, as it was with that arm he was most experienced. A team of six horses was the greatest number manageable per gun, and there ought not to be more than 30 cwt. behind the six. It had occurred to him that by good mechanism there might be an advantage in taking weight out of the carriage and putting it into the gun; but 30 cwt. must not be exceeded for the horses.

Mr. Cowper.

Mr. E. A. Cowper observed that although the Author had stated that a sufficient number of experiments had not yet been made to enable one to calculate in every possible way, the different strains and results, still he had gone a long way towards pointing out the right direction, in which the desired information might be ascertained, and also the way in which the strains on a field gun-carriage could be greatly reduced. He had spoken of a wave line, in place of a steady line being produced by the indicating instrument. Mr. Cowper, before commencing the use of the indicator, had taken care to ascertain, that a line drawn through the waves represented truly the same power as the waves themselves, and he had come to the same conclusion as the Author. It was merely the fluctuations of the spring of the indicator, moving with the weight of the piston, as in the ordinary balance of a watch; a certain weight vibrating with a certain strength of spring. It was a simple point, and he was glad that a right understanding had been come to upon it. He felt considerable interest in the arrangement for a "hydraulic buffer." He took, however, some

Digitized by Google

exception to the term "elastic" field gun-carriage; it was more like a "dead resistance" field gun-carriage. It was, in fact, a gun-carriage with a certain amount of "give" in it. The gun could run back on the carriage a certain distance, before it made the carriage run; and however strong the gun-carriage might be made, it would be less strained by the gun in its recoil, if a certain amount of dead resistance was opposed to the gun before it struck the carriage. He did not find in the Paper the name of the inventor who first brought forward the "hydraulic buffer." Dr. Siemens was consulted some time ago by the authorities as to the best mode of causing a resistance, and he suggested that the best way would be, to put in a hydraulic buffer. Mr. Cowper took the more interest in the subject because many years ago the same idea had occurred to him in reference to a totally different matter. In 1846 a bad railway accident occurred from a train running into a station buffer. He then schemed a buffer to allow 9 or 10 feet recoil, with a water cylinder and piston to run back in the same way. Dr. Siemens, however, knew nothing of the plan he had proposed. The resistance, of course, could be increased, as had been clearly pointed out in the Paper, by the addition of taper rods through the piston, so that, as the piston went home, the area through the holes was reduced, because the rod, being larger, occupied more space. The resistance was kept up throughout the whole length of the stroke, although the stroke was much quicker at the commencement and slower at the end. In that way more work was done in the same length. If complete experiments were made to ascertain all the facts affecting the recoil of guns, he should like much to analyse them, and see if the result of all the forces, after proper deductions had been made, agreed with the results obtained. He would ask the Author to furnish such results to the Institution if they should be obtained, for he thought that further experiments were necessary, and he felt sure that they would now be made in the cause of science and the practical interests of the country. Several data were wanting. One of them was the gas-pressure acting inside the gun against the breech, until such pressure had died away. He wanted to see the line continued until it showed no pressure in the gun. It was certain that after the shot had left the gun, the gun acted as a rocket; there was an enormous quantity of dense compressed gas equal to the weight of the powder inside, which issued from the muzzle with great force, and continued to press back and cause an acceleration of speed in the recoil. That force had not yet been calculated. Then there was a deduction to be made on account

Mr. Cowper.

Digitized by Google

Mr. Cowper. of the friction of the powder-gas against the sides of the bore of the gun while driving the shot, and while escaping after the shot was out; that was a friction tending to urge the gun forward, and not backward. Then there was the friction of the gas check, also tending to urge the gun forward. The gas check was driven against the bottom of the shot or shell with considerable force, and there was a great deal of friction. Then there was the friction of the shot itself while rushing along, also tending to pull the gun forward. There was further the pressure required to set up the quick rotation of a shot in rifled ordnance, due to the *vis inertia* of the shot, and the friction caused thereby against the grooves in the gun, which also tended to pull the gun forward. The last, he was persuaded, amounted to a considerable deduction from the force tending to cause recoil. He might mention that, having had to make the working drawings of the first rifling machine constructed, for boring out the first Lancaster gun, according to Lancaster's design, he saw the evil that might result from giving too much pressure against the grooves, particularly if the rifling was with an increasing pitch. He felt a great interest in the gun, and took a fortnight to bore it out. In practice it was found that from the rapid twist given to the shot towards the muzzle of the gun, some damage was done to the muzzle from the tearing action of the shot going out; that showed the enormous friction against the sides of the gun, which should be taken as a reduction from the total recoil. It was well known that plugs inserted into the shot to take the grooves in the gun were sometimes torn off, and this also proved the severity of the strain. He agreed with the Author that simply gauging the greatest pressure could not be correct, and that it was necessary to take into account the pressure acting against the inside of the breech for each instant, until the whole force ceased. The total of all those efforts, minus the efforts to produce a forward motion, would be the amount of force causing the recoil. In conclusion, he might say that a most interesting experiment would be, to separate the forces tending to pull the gun forward, from those tending to cause recoil, and that might be done by separating the breech from the bore of the gun, by making the breech-piece like a piston, to fit inside the bore, the piece having as much weight behind it as the total weight of the gun; the friction of the shot, gas check, &c., would all act on the bore of the gun to pull it forward to a certain extent, and the motion could be measured. There was another point that he should like to see brought out, namely, the exact times of the pressures in the gun, compared with the exact times of recoil.

Digitized by Google

Mr. Cowper. He could not help taking a little exception to the apparatus for registering the recoil as presenting some chances of shake and elasticity. He should like to see a hole drilled in the trunnion itself, and the pencil placed in it, and the paper placed on the cylinder opposite to it, so that there should be no elasticity between the paper and the gun. He should like to see the powder-pressure registered accurately for time on the same paper, or another paper geared to it, to learn precisely what the pressure was, at each instant of time, in comparison with the exact time of recoil. He could not think that the gun ever moved instantaneously at a high speed; it must, he thought, show a curve on a properly constructed instrument for the starting, as well as the stopping, of the recoil. In that way it might be found out exactly when the recoil commenced. He thought that the gun began to move, as soon as the gas-pressure inside it was equal to the friction of the moving mass. The exact times of the pressures, and of the shot passing the "pressure-plugs," could be registered by pencils stationed over the paper cylinder, and acted upon electrically, from wires reaching down inside the pressure-plugs to very near their ends, so that a slight motion for "contact" could be got from the wires.

Prof. Unwin. Professor UNWIN said the Paper contained a vast number of extremely interesting facts which the members might all accept whether they agreed with the Author's *rationale* or not. The facts had been observed in circumstances of great difficulty, and apparently with great care; and the Paper certainly showed that in the development of artillery at Woolwich, valuable observations had been made. But there could be no doubt that some statements in the Paper appeared to put in question the equality of action and reaction; and if that had to be given up, he was afraid that a good deal of mathematics would have to be re-written. He was disposed to accept every fact that the Author had stated as being accurately recorded, without, however, accepting his explanation. The Author had pointed out that the velocity of the recoil of the gun had been calculated by assuming the equality of the forward momentum given to a shot, and the backward momentum given to the gun. According to the formula,

$$W V = w v,$$

and that result appeared to be based upon the third law of motion. In the interpretation of that, the whole question to be determined was what value was to be assigned to the symbols. With regard to the two V's there could be no doubt; but about the two W's

Digitized by Google

Prof. Unwin. there might be a difference of opinion. All that the law of equality of momenta taught was that the whole forward momentum given to the shot, to the powder charge, and to the air surrounding the shot must be equal to the whole of the backward momentum given to the gun, to the gun-carriage, and to any bodies which were put into motion backwards; and the equation would not be rightly formed unless there were introduced on the one side, in addition to the weight of the shot, that portion of momentum which belonged to bodies accompanying the shot in forward motion; and, on the other side, not only the weight of the gun, but the weight of those bodies which accompanied the gun in backward motion. Taking the case of a ballistic pendulum, the gun was so suspended that in that case the conditions were most nearly approached in which W might be taken to be the weight of the gun alone, and w the weight of the shot alone. Another extreme case would be obtained if a gun were supposed fixed absolutely rigidly by a sufficiently large block to the earth. In that case, the shot would have the same forward momentum as before; and there would, apparently, be no backward momentum at all. But, of course, the backward momentum would have to be calculated by making W equal to the whole mass of the earth, or, at all events, to a large portion of it. The actual case of a gun and a carriage was intermediate between those two cases, the W was not simply the weight of the gun, but the weight of the gun *plus* certain weights which, in the ordinary use of the equation, had not been introduced into it.

The gun-carriage by its frictional connection with the ground imparted some momentum to the earth while acquiring its maximum velocity of recoil, and on the other hand the shot and powder-gas escaping from the gun gave forward momentum to a mass of air, the weight of which was not negligable in comparison with the weight of the shot. Probably the larger volume of powder-gas in the case of pebble powder, and its slower escape from the gun, caused a larger mass of air to be put into forward motion, and thus the greater recoil with pebble powder might be explained. It might be pointed out that the equality of the forward and backward momentum was independent of all such mutual actions between the shot and the gun, as the friction of the shot on the gun, or the pressure against the rifling. Those actions were balanced. The forward drag of the shot on the gun was equal to the backward drag of the gun on the shot, and the forward and backward momentum were equally affected.

Dr Siemens. Dr. SIEMENS thoroughly agreed with the mathematical proposition put forward by Professor Unwin, which, indeed, admitted of no

Digitized by Google

doubt. At the same time, as Mr. Cowper had already pointed out, there were great deductions to be made. All the friction had to go in reduction of recoil, and that friction must necessarily be largest at the commencement of the action when the charge was rammed tight home. Then, again, the friction of the gun-carriage upon the ground might be very considerable, and that had to go in reduction; so that theory and practice, as propounded, and so well argued by the Author, seemed to agree nearly enough for general acceptance. He should like to add a word with regard to an observation from Mr. Cowper regarding his connection with the question of hydraulic compressors. All that Dr. Siemens could claim was the mere suggestion of hydraulic compression for gun-carriages, and that had been gracefully acknowledged by the then head of the department (Colonel, now Sir Andrew, Clarke, K.C.M.G., C.B., Assoc. Inst. C.E.), in a Paper, read about a year after the suggestion was made, before the British Association. The fact of his suggestion, however, in no way detracted from the great merit due to the officers of Woolwich, and especially to the Author, for the thorough way in which the hydraulic pressure had been worked out for stationary guns, and had been now brought forward as applicable to field guns. He could not help thinking that the term "elastic gun" was unfortunate, because it gave a wrong idea. Although the Author had explained that it meant only one portion of the elastic action without the elastic rebound, it was essentially an inappropriate name. One question which presented itself was whether the hydraulic compressor applied to a field-gun was a complication. It was, unquestionably an additional part; but he did not think that every additional part to a machine meant a complication. If by the addition of 1 cwt. 1 ton could be saved without subjecting any portion of the material to a greater strain, that really meant simplification; an effect was produced with less weight of machinery. The hydraulic cylinder with a single piston was an extremely simple mechanism. No valves were connected with it; there was nothing that could possibly take harm; and he believed that Colonel Shakspear would have found that a gun of that description would not come to any harm from the rough usage to which he had alluded; and after it had fallen would have been more readily put on its wheels again than the older form. The Author's proposal was a move essentially in the right direction—the lightening the material of the field-gun—and he thought it was done without complication, if complication meant liability to get out of order.

Dr. Siemens.

Rev. JAMES WHITE, M.A. (Head Master of the Royal Naval

Rev. J. White.

Digitized by Google

Rev. J. White. School), thought that the effect of the air had been completely taken into consideration by the manner in which the results had been obtained—from observing the velocity of the recoil and the velocity of the shot. In considering those elements account had been taken of the effect of the air, both upon the carriage and the shot, at least as far as the force of velocity was exerted, for the force of velocity was determined by the medium through which the projectile passed and also through which the carriage recoiled. He did not think that, apart from the effect of velocity, much effect was produced by the explosion of powder upon the air, at least not much effect in producing a recoil upon the gun. He made those observations for the following reasons. He had witnessed many of the experiments made with Colonel Moncrieff's gun-carriage. That carriage, which was remarkable in many ways, was also particularly interesting as exhibiting many new conditions. He referred to the counterweight-carriage and the hydro-pneumatic carriage. In both, especially in the counterweight-carriage, there was no resistance proper to the recoil at first, or almost none; the centre of gravity of the whole mass hardly moved at the first motion of the gun. That was one reason why it was unsuccessful in solving the problem which had been attempted frequently before without success, namely, that of meeting recoil without dangerous results. At the first motion of the gun there was hardly any resistance; the centre of gravity of the whole mass was hardly moved, and the counterweight merely got a very slight horizontal motion. It was only when the recoil advanced that the counterweight lifted, and the centre of gravity of the whole mass altered. When the gun was fired with a blank cartridge there was very little recoil indeed, the gun hardly moved, and from that it seemed clear that the action of the exploding gas upon the air produced but a very small effect. Therefore the effect of the air and the gas upon it might be considered as accounted for in the velocity which resulted both in the shot and in the gun; he did not imagine that any other estimate of it was required. He might also observe that the expanding gas, when there was a blank charge, produced very little recoil, and the reason seemed clear; the gas, when it expanded, did not meet with a large mass of some resisting medium, but met with a highly elastic medium—the air, and it diffused itself through the air. Therefore he did not think that the resistance or the effect of the air need be taken further into consideration in estimating the velocities of the gun in its recoil and of the projectile in its flight. Gun-cotton, although it strained the gun heavily, produced but

Digitized by Google

very slight recoil, because its action was so rapid. In Colonel Moncrieff's carriage hardly any recoil was produced, not sufficient to carry out experiments to show what the effect would be when gunpowder was used. The action of the exploding gunpowder upon the air was not really the action developed in a rocket; that was brought about slowly, and therefore it produced a continual push, as it were, to send the rocket forward. That was not the case in the explosion of a cartridge in a gun. The gas in the rocket was produced during a good number of seconds of the rocket's flight, and the time of moving the projectile was estimated in ten-thousandths of a second, so that there was a very great difference between the two. He thought that in estimating the effects of recoil all that was necessary with regard to the air was to take into consideration the velocity imparted to the shot and the velocity of the recoil of the gun. It appeared to him also that the important question of the laws of motion was hardly affected by the subject under consideration. The great law of motion—that action and reaction were equal—was not touched. The action of the gunpowder upon the shot gave a certain momentum, but it did not follow that the effect upon the gun was also a corresponding momentum, because the reaction had other things to do besides producing the motion of a certain mass; it had to heat a much larger body than the shot, and some of the reaction was expended in that way. Other molecular changes might be brought about. No doubt action and reaction were equal; but it appeared that the subject had been dealt with in the Paper entirely from the point of observation, and that the great laws of motion, especially the important law of action and reaction, were not touched by the question under discussion. There seemed to be some confusion with regard to the expressions "statical" and "dynamical" force. The two things were very different; but in touching those subjects, it should be remembered that these things were taken as they were in idea, and not as they were in fact. Though statical and dynamical force were very dissimilar in idea, sometimes in practice there was a border-line between them which it was not easy to distinguish. For example, if a weight was laid upon a spring, that was a statical force, pressure; yet, however gently the weight might be laid upon the spring, there was always something of a dynamical effect produced—the spring would always go a little below the point at which it would remain. Sometimes the force, quasi-statical, involved a dynamical force operating very slowly. It was a confusion in terms; it did not necessarily imply confusion in ideas.

Rev. J. White.

Digitized by Google

Rev. J. White. Persons who taught mathematics were apt to forget that they were dealing with ideal conditions, and that practically men might make use of terms which to teachers might seem confused, but which did not necessarily imply a confusion of ideas on the part of persons using them. Although it was desirable that language should be always correct, and it should be remembered that statical and dynamical forces were distinct, it was almost as important for professors to remember that in teaching mechanics especially, they were dealing with conditions that never actually existed. For example, every manual of mechanics began by informing the learner that a bar was spoken of as perfectly rigid, and that there was no such bar in nature as that which he was desired to imagine.

Mr. Bousfield. Mr. W. R. BOUSFIELD said that his criticisms might be considered a little uncharitable in view of the great practical value of the Author's Paper; but he could not help thinking, in regard to the theory of the subject, that the Author had gone astray. The Author had explained how the powder acted on the shot. No doubt it produced a compression on the base, as he had stated, and no doubt also, it produced a permanent compression in some cases if the pressure were very great; but he could not agree with what the Author said in speaking of the action of the powder-pressure upon the gun. He imagined it would be very difficult to ascertain in practice at what point motion was set up. He also demurred to the way in which the Author had spoken of overcoming inertia. He spoke of time being an element in overcoming inertia. Of course, it was an essential element; but in the sense meant by the Author he thought it was not essential. Take the case of a constant force acting upon a certain mass. The overcoming of inertia meant the setting up a certain velocity in the mass. Whether the first ten-thousandth of a second were taken or the ten-thousandth of a second after the force had been acting two or three minutes, the amount of velocity set up in that short interval of time was exactly the same; the effect of overcoming inertia was exactly the same in the same interval at whatever point of time it was taken. Inertia (if the word had any scientific meaning—which he much doubted) was no greater when the force began to act than when it continued to act. It was a simple question of being able to perceive the motion which was set up. He thought that the way in which the overcoming of inertia had been spoken of rather tended to lead astray than to give any true theoretical view of the subject. Of course, in considering the impact of an inelastic body, mathematicians divided the time of the impact into two periods, the period of compression and the

Digitized by Google

period of restitution; but, in this case, the two bodies were close together and re-acting on one another. The Author appeared to have taken some formula, or principle of equality of momentum, (a principle which did not exist in a scientific point of view), and did not find it fit in with the facts before him; he had therefore adopted the theory that the velocity of the gun did not begin to be set up during the first part of the powder action; but that the effect of the powder-pressure was simply to stretch the gun longitudinally, and that the velocity of the gun was due to the effect of this longitudinal stretching after the shot had left the gun, and all external forces had ceased to act. That was equivalent to saying that a system of particles with various strains acting between them could be moved as a whole by the inter-action of these forces inside the system of particles. This was a startling proposition to any one acquainted with the fundamental principles of mechanics, that the recoil of a gun could be due to some state of strain which existed in it, and that that state of strain could set up a velocity independently of any external force. He did not think that in order to explain away an unscientific formula and its discrepancies, mathematicians were called upon to accept any theory of that kind, which was far more unscientific than the formula itself. What was the true way of looking at the subject? Instead of going back upon some principle of equality of momenta or equality of energies (of which he knew nothing), or some principle of inertia, it would be better to fall back upon the laws of motion referred to by Mr. White, which were sufficient to account for all the facts observed. Newton's second law of motion was that change of momentum was proportional to the acting force. No doubt the principle of equality of momenta might be supposed to be an expression of that second law; but it was nothing of the kind. He thought that the Author had left out of consideration two or three most important elements which entered into the subject. One reason why the formula taken by the Author was not correct was that the effect of the resistance of the ground, or of a trunnion, or of whatever resistance might be acting upon the gun, had not been considered. Secondly, the Author had only taken into account (in the case where he had taken the weight of the gun as being one hundred and thirty-four times the weight of the shot) the weight of the gun itself and not the weight of the carriage. Thirdly, he had neglected the effect of the discharge of the gaseous contents of the gun, which Mr. White thought might rightly be neglected, but which Mr. Bousfield thought ought to be taken into consideration. The time during which the forces were acting ought to be divided into

Mr. Bousfield.

Digitized by Google

Mr. Bousfield. two periods: first, the period while the shot was in the gun up to the point when it left the muzzle, and next the period after the shot had left the gun; for he believed that while the gun was being emptied of gases there was a considerable effect. Taking the expression of the second law of motion, that change of momentum was proportional to the acting force, what was the change of momentum? Taking the direction of motion of the shot as the positive direction, the change of momentum during the time the shot was travelling from the breech to the muzzle would be

$$m v - \mathrm{M V},$$

where m M were the masses of the shot and gun respectively, and v V their respective velocities at the moment the shot left the muzzle. The so-called principle of equality of momenta assumed that $m v - \mathrm{M V} = 0$; but Newton's second law said that this expression, which was the change of momentum, was proportional to the whole forces acting during the time. By a simple application of that law the following equation therefore was obtained:—

$$m v - \mathrm{M V} = \int_{t_0}^{t_1} (\mathrm{R} - \mathrm{S})\, \delta t,$$

where R was the resistance acting upon the trunnions, and S the resistance of the air to the shot, whilst in the bore of the gun; t_0, t_1 being the respective times of the explosion and of the shot emerging. When the shot had left the gun, the motion of the gun was given by the formula—

$$\mathrm{M} \frac{d^2 x}{d t^2} = \mathrm{P} - \mathrm{R},$$

P being the pressure on the breech due to the reaction of the escaping gases. Thus the time when the gun had its maximum velocity was determined by putting

$$\frac{d^2 x}{d t^2} = o;$$

in other words, it was a maximum when R, the resistance on the trunnion, was equal to P, the internal pressure on the breech, of the escaping gases. After this the velocity of recoil diminished, and was given at any future time t by the equation

$$\mathrm{M} \frac{d x}{d t} = \mathrm{M V} + \int_{t_1}^{t} (\mathrm{P} - \mathrm{R})\, \delta t.$$

If the resistance S and P of the air were neglected, then the velocity V at any time t would be given by

$$m v - \mathrm{M V} = \int_{t_0}^{t} \mathrm{R}\, \delta t.$$

Digitized by Google

Since the area of the curve obtained by the Author from the pressures of his hydraulic buffer was the $\int R\,\delta t$, obviously the last formula could be applied as an approximation, which he ventured to think would be nearer and more generally applicable than putting in the arbitrary factor $\frac{3}{4}$ suggested by the Author. Mr. Bousfield.

In that way, without upsetting the theory of conservation of energy and other theories, the facts could be accounted for on ordinary mechanical principles without supposing that a system of particles acted on by no external force, but simply by internal strains, could generate motion on its own account. He might be permitted to make an observation on the form of the cylinder which the Author used. He thought it might be advantageous, instead of having holes in the piston with gradually tapering rods put into them in order to regulate the pressure as the gun went backwards, to have a return tube for the water alongside the hydraulic cylinder, with a series of holes, along the cylinder into this return tube, which would be gradually closed as the piston receded.

In accounting for the difference of recoil with R. L. G. powder and with pebble powder, the Author stated that, with slow burning powder, the recoil was perhaps a third greater. The Author had stated that the R. L. G. quick-burning powder set up a molecular action, and that a great deal was wasted in that way. No doubt, as Mr. White had stated, much of the energy which might go into the recoil was used up as heat. Of course there was a greater compression of the gun than of the shot, and compression always meant, to a certain extent, in dealing with elastic bodies, generation of heat, and this would take place to a greater extent on the large mass of the gun than it would on the shot; that, however, was small, and might be left out of the account. He believed that the difference in the times was due to the fact that the pebble-powder was not completely consumed at the time the shot left the gun, and that the result was due to the second of the two periods to which he had referred. A considerable quantity of the powder not having been burnt when the shot left the gun, it still remained to be burned, and it was the additional action due to this burning after the shot had left the gun that set up the additional recoil. The weights of the powder used in the Author's experiments, 60 and 70 lbs. respectively, would account for it to a great extent, because the energy communicated to the shot being the same in both cases,

Digitized by Google

Mr. Bousfield. it followed that a larger energy would be communicated to the gun in the latter case. As to the practical value of the Paper there could be no doubt. He had only ventured to remark upon the theory of the question, because he thought progress was impeded when a wrong theoretical view was taken.

Commander Dawson. Commander W. DAWSON, R.N., from what he could make out in the Paper, considered that the forces and strains on the carriage were to be measured by the length and time of the recoil. It appeared to him that the reverse of that proposition was true—that the strains and forces of recoil upon the carriage were in an inverse ratio to the length and time of recoil. If two railway trucks were placed on two pairs of rails, and if one was struck with such a sudden impact as to shiver the structure, and the other was pushed gently with a force the sum of which would equal the impact, he submitted that the recoil of the one which was pushed gently would be longer by many hundred yards than the recoil of the other which had been struck by a sudden impact so as to injure the carriage. In which case were the greatest forces and strains on the wagon? Was it not on the one that had been struck sharply and had a short recoil, and not upon the one which had a long recoil? It was a great loss to the country, and to individuals, that seamen who had to use carriages and guns were brought so little in contact with engineers who made them, and from whom they might learn a good deal, especially in the matter of taking observations. Interesting results often passed before their eyes which, for want of accuracy of observation, were of no value to the world at large nor to themselves. If they were taught to make accurate observations they might perhaps be able to give engineers more useful hints than they could give at present. It had been his lot to have the responsible charge of firing nine thousand or ten thousand shot, not at Shoeburyness or Woolwich, but under more trying circumstances on board ship. He had seen accidents occur, carriages disabled, platforms disabled, the deck beams and planks injured, and the like, and he had observed that when those accidents occurred there was generally a very short, not a long recoil. There were of course occasions in which the recoil was long, and in which the tackle of the gun gave way; but in the majority of cases when the carriages or decks were injured the recoil was short. That, he believed, was due to the degree of violence with which the gunpowder acted. The same charge of gunpowder did not always produce the same amount of recoil; it depended upon varying circumstances, such as the condition of the atmosphere, and the number of charges

Digitized by Google

that had been discharged from the gun during the same day—in other words, upon the heat of the gun. If the gun were warm the gunpowder acted very violently and the recoil was greater. Again, if the gun were elevated a few degrees it would be found that the strains and forces of recoil were much greater than when the gun was fired horizontally. If the platform opposed much friction, or was on a plane inclined upwards at the rear of the gun, the force of recoil would be greater, the strains upon the carriage would be greater, and when the carriage gave way, it was generally all those circumstances acting in conjunction over and above the ordinary action of gunpowder that brought about the result. Every sportsman knew that in discharging his fowling-piece rapidly it became heated, and kicked more violently, and if he fired it in an elevated position his shoulder felt the recoil more than when he fired horizontally. There had been some recent experiments in reference to recoil, of which he had hoped to find details in the Paper, but the subject remained, for all practical purposes, uninvestigated; and that was his apology for giving his experience as a seaman. The statement in the Paper to which he took exception was, "That slow-burning powders, by acting more gradually in overcoming the inertia of the gun than quick-burning powders, induce a greater energy of recoil, in the proportion of the longer intervals of time during which they act upon the gun; and this notwithstanding that the energies imparted to the projectiles are the same." The remarks of Mr. White as to gun-cotton completely answered that statement. Gun-cotton was quick in combustion, and the recoil was small. The power that it exerted was tremendous, so that the recoil could not be taken as a measure of the straining or force which the gun-carriage had to bear. With regard to the practical proposal of the Author, there could be no question as to its value; but he hoped that engineers would take into consideration the difficulties that had to be encountered, and remember that they were not always playing at soldiering in the marshes at Woolwich. Whatever elastic buffer might be used, its strength should be computed, not with reference to a cold gun fired horizontally, but to its action when fired in a heated condition, at a high elevation, or with an inclined plane under the base of the carriage. It had been suggested that a spare buffer might be carried, in case of failure of the first; but he should prefer making the first buffer so strong that it would not get out of order.

Commander Dawson.

Mr. B. WALKER said the first object of the Paper appeared to be to bring before the members a new arrangement of field gun, which

Mr. Walker.

Digitized by Google

Mr. Walker. the Author called an elastic field gun, and which was to weigh less than field guns had hitherto weighed, to cost less, and to be less liable to get out of order. He thought the carriage illustrated in Fig. 8 was an admirable specimen, and likely to do good service. It had just been suggested that the buffers should be made so strong that a spare one would not be wanted. No doubt that would be very desirable, if it were possible to make a mechanical instrument that would never go wrong, but it would be a very difficult problem. Dr. Siemens had claimed to be the first to mention to the authorities of the Carriage Department the use of water as a means of controlling the violent action of gunpowder. The Department had wisely asked his advice, and had suggested the use of galvanism or electricity. Dr. Siemens told them that he had too much knowledge of the uncertainty of electricity and galvanism to recommend its adoption, and he suggested water as a means of moderating the action of gunpowder. It would be well within Dr. Siemens' knowledge at that time that water had been used to check the violent jerky action of large steam valves, by allowing the water to pass through a specified orifice, the same water being used to control the closing of the valve by letting it go through another orifice in a definite time. He had no doubt the Author was also well acquainted with a contrivance called a cataract motion. There was another contrivance, namely, two or three pumps working into a vessel, the water passing out of a small definite hole. If the pumps went too fast the pressure was increased, and by that means the throttle valve of the steam engine was closed. The Author and Dr. Siemens would no doubt both have the notion that the water would have to pass through a specified orifice, and so regulate or absorb the violent jerky action of the gun. It would be difficult to imagine any contrivance in which the parts were less liable to get out of order, or in which the arrangement was more simple and ingenious. He had long been familiar with the fact that in using a hydraulic pump, or any means for getting pressure, a vibratory action was shown by the indicator, such as that referred to by the Author, but he had never before seen the matter brought out so simply and plainly. Mr. Walker had frequently noticed when testing boilers or hydraulic cylinders, that a slight movement of the hand-pump gave a vibratory motion to the pressure-gauge, sending it above the pressure that could possibly be reached in the cylinder, and likewise depressing it an equal distance below. He had himself followed the practice of shutting the valve between the pump and the pressure-gauge to reduce the vibratory action on the pressure-gauge. He had

Digitized by Google

found, over and over again, that he did not get all the pressure that he should have got according to the indicator card, and he believed that some light was thrown upon the question by the facts mentioned by the Author. Mr. Walker

Mr. W. E. RICH said he had studied the question of recoil and how best to resist it some years ago, when engaged on designs for Moncrieff hydro-pneumatic gun-carriages made by his firm for the English Government, and also some 40-ton gun-carriages on the hydraulic disappearing principle for Russia. He thought that the recoil of guns should be taken up by a resistance very small at first, and increasing rapidly. The resistance which took up recoil in ordinary guns might be considered practically uniform, disregarding the resistance of the molecules and particles of the gun itself. Clarke's system of hydraulic buffers seemed to him, in its usual application, to be subversive of the principles that ought to govern such designs, inasmuch as the resistance was enormous to begin with, and rapidly fell with a hollow curve to a small amount towards the end. In the Russian carriages of which he had spoken, the recoil was taken up by loading a safety valve with springs increasing the pressure as the gun went down, and in the hydro-pneumatic Moncrieff carriages the recoil was taken up by a pressure increased by the compression of the air in a cylinder partly filled with air and partly with water. Mr. Rich.

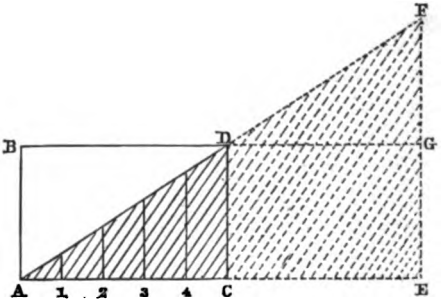
Sir FREDERICK BRAMWELL, Vice-President, remarked that many subjects had been brought forward in the Paper into which he was not prepared to enter, but there was one point upon which he should like to speak, and that was upon the question of the possible strain on the trunnion of a gun. He must confess that he at one time entertained the opinion that in no case could that strain possibly exceed that due to the area of the bore multiplied by the maximum pressure per square inch, and he had suggested as a test that if a gun had a bore of, say, 100 inches area, and a maximum pressure of, say, 17 tons per inch, then if that gun was placed over a well with its mouth downwards, and its trunnions were loaded with a weight which, added to that of the gun, exceeded in the least the 1,700 tons of pressure on the whole area of the bore, the gun could not rise; or in other words, that it was clear the maximum strain on the trunnion could not exceed in the case supposed the 1,700 tons. Further consideration of the matter had, however, led him to the conclusion that this strain might be considerably exceeded, and that, in a certain assumed event, which, however, could never happen in practice, the strain might be doubled; and in order to show the principle he had in his mind he Sir F. Bramwell.

Digitized by Google

Sir F. Bramwell.

would ask the members to consider the assumed instance, which was that the maximum powder-pressure might be generated all at once without requiring any appreciable interval of time before that pressure was reached, and, secondly, that it might remain constant for the brief period during which the stretching (of which he was about to speak) of the material of the gun longitudinally between the base of the bore and the trunnion was going on.

FIG. 1.



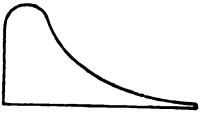
Let the vertical line A B in the Figure represent the maximum powder-pressure, and continuing uniformly during the whole time that the elastic material of the gun was extending say through A C to the point C, where it was to be assumed it would be capable of resisting a strain equal to A B, then the work done by the pressure would be represented by the parallelogram A B D C; but the work expended in the elastic material, if, as was assumed, the resistance offered to stretching increased regularly as shown by the vertical lines 1, 2, 3, 4 would only be that represented by the cross-lined triangle A C D, or one half the work done; the stretching of the material must therefore be continued until the area of the triangle representing the work of resistance of the spring was equal to that of the parallelogram representing the work done by the pressure on the bore moving through the space allowed by the yielding of the material, and this would obviously be when the strain upon the material was double that upon the bore as shown by the vertical line E G F, for not till then would the triangle A F E be equal to the parallelogram A B G E. He was well aware that in practice no such double strain would arise. The pressure was not generated absolutely instantaneously, the trunnions were not rigidly fixed, and the weight of the elastic material set in motion had to be considered; but nevertheless he thought he had stated enough to show how it was possible that the strain produced

Digitized by Google

by the powder on the bore of the gun might be exceeded at the trunnion. With respect to one of the main points brought forward by the Author, viz., that with large grain powder it appeared there was a greater velocity of recoil than with pebble powder, the velocity of the shot being the same, he wished to remark that, as the Author had stated, there was about one-sixth more pebble than the R. L. G. powder employed, and that this in itself accounted for some of the difference; but irrespective of that he should be inclined to adopt Mr. Cowper's statement as to the effect of the gases in the gun escaping after the shot had left. It did not appear to him that the Author had given due value to that effect. He did not agree with Mr. Cowper as to the deductions to be made in the way of friction, because it appeared to him that friction equally operated in retarding the outgoing of the shot, and that when comparing the velocity of the shot into its weight, and the velocity of the gun with its carriage into their weight, it would be seen that friction had already been taken into account in both, and that therefore the deductions mentioned by Mr. Cowper ought not to be made. But he thought he was right in saying that when the R. L. G. powder was used, with rapid combustion, a pressure was generated in the gun greater than that generated by the combustion of pebble powder, but not lasting so long and having a low terminal pressure. In a diagram the R. L. G. powder might be represented by a curve, Fig. 2, and the pebble powder by a curve, Fig. 3. Where pebble powder was used there was, he thought, a larger pressure remaining in the gun at the time the shot left it, than there was at the corresponding time in the case of large grain powder. If that were so, ought there not properly to be taken into account, as one of the elements in causing the recoil of the carriage, the weight of the gases in the gun escaping after the shot had left with the enormous velocity due to the ultimate pressure of some 2 tons to the square inch? If that velocity was taken into account, and multiplied into the weight of the powder, would not that be quite sufficient to account for the extra recoil or velocity of the gun, when pebble powder was used, over and above the recoil that prevailed when rifle large grain gunpowder was used? He exhibited a model bearing on the subject—a gun weighing five times the weight of the shot. The shot and the gun were both mounted on wheels; there was a revolving cylinder alongside, and

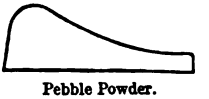
Sir F. Bramwell.

FIG. 2.



R. L. G. Powder.

FIG. 3.



Pebble Powder.

Digitized by Google

Sir F. Bramwell. each traced its recoil upon the cylinder. He had before him two papers, the curves on which had been drawn by the action of the apparatus, but as they had only been obtained just before the meeting, he had not had time to examine them, and did not feel justified in drawing any conclusion from the records they afforded.

Mr. Barlow. Mr. W. H. BARLOW, Past-President, felt a little difficulty in reconciling the observations of Sir Frederick Bramwell with the intelligent remarks made by Mr. White. It was difficult to understand how altering the position of the trunnions of a gun could alter very materially the action of the gun upon its trunnions. It appeared to him, looking at the subject of the Paper generally, that if the endeavour was made to treat it mathematically, it became so minute in its conceptions and so difficult to follow, that he should prefer to be guided by the results of experiments rather than by the results of theory. He had been born and bred in a mathematical atmosphere, and he had seen the sinuosities of mind which were required to follow out calculations of that kind, and conditions came on which he might term a mathematical haze. He really thought that when mathematicians attempted to enter into those very fine points, and to measure time by millionths of a second, they were getting rather lost. Instead of entering into any arguments on theory, he should be prepared to see what would be the result of experiments on the Author's gun-carriage. It was quite new, and it involved principles that he did not think any one could exactly follow out at the moment, and he therefore preferred to wait till the Author had submitted it to experiments before determining what the results of those experiments would be.

Mr. Bousfield. Mr. BOUSFIELD said he had not intended to advance a complete mathematical theory, but only wished to show that, by omitting one side of the equation, the Author had been obliged to elaborate some molecular theory to account for the absence of it; and that, by putting in the other side of the equation, the facts might be accounted for by the second law of motion without going into any such theory.

Mr. Barlow. Mr. W. H. BARLOW replied that it appeared to him that Mr. Bousfield had treated the gun as being perfectly rigid, whereas, in fact, it was elastic.

Mr. Butter. Mr. BUTTER, in reply, said the discussion had taken two distinct lines: one, adopted by engineers, who were also mathematicians, was entirely practical, in exact conformity with the spirit of the Paper, and such as might be expected from those whose daily experience brought them into direct contact with the conditions governing action and reaction; while the mathematicians who

Digitized by Google

had favoured him with their critical observations (except Mr. White) had insisted upon the sufficiency of mathematical expressions to meet the case, ignoring the difference between actual and ideal conditions; he had taken especial care to point out that the question was not ripe for exact mathematical investigation on account of the absence of sufficiently accurate observations, and on this account he had not wasted time nor confused the subject by introducing any of the higher modes of calculation. By purely empirical methods, embracing the results of reliable observation, and founded on the formula for the equality of momenta, which for generations had been used for finding the velocity of recoil, he had constructed a simple expression for practical use, of the sufficient accuracy of which for practical purposes he had no doubt. From the interest shown in the Paper it was manifest that another object he had in view would be attained, namely, the directing attention so forcibly to the subject as must lead to observations being made which would place the question in a much more satisfactory condition than he had been able to do from the poverty of his resources. Mr. Butter.

He would first direct attention to what he would call the "practical line," and afterwards deal with the "theoretical" one.

He must acknowledge Mr. Cowper's ready acceptance of his experimental results of the time and space values of pressure diagrams; these he knew quite well brought no new facts to light, but he was not aware that they had been so conclusively demonstrated by experiment. He was also gratified that Sir F. Bramwell and Mr. Cowper agreed with him that the maximum pressure of recoil might under certain conditions exceed the maximum powder-pressure on the bottom of the bore, and that the latter gentleman had stated his belief in the gradual increase to its maximum of the velocity of recoil—a fact which Mr. Butter believed had not been brought forward before. With respect to the invention of the hydraulic buffer, Dr. Siemens had undoubtedly suggested the idea of using fluids, and his thanks were due to him for the terms in which he had alluded to this part of the subject. Dr. Siemens had taken exception to the title adopted for the new carriage, but when it was first designed it had a steel spring inside the buffer the object of which was to restore the gun into the firing position, and thus the complete action was truly elastic. This spring might yet be found to be necessary, but if the reaction of the body of the carriage, assisted by gravity, was found to be sufficient to restore the gun into its original position, it would be better to dispense with the spring. On a due consideration of the

Digitized by Google

Mr. Butter. subject it would be found that no single word could be selected which would better express the object of the apparatus, which was to give that "yield" to the carriage, and by other means restore the "form," which were the peculiar features of elasticity. Colonel Shakespear and Captain Dawson had somewhat mistaken the sense in which the length of recoil was alluded to in the Paper. The carriage was not expected to affect the length of recoil whatever, but was designed to reduce the strain. Allusion had been made by Mr. Rich to a feature of the simple and the original form of the hydraulic buffer—the great pressure at the beginning of recoil—as being "subversive of the principles that ought to govern such designs." He was apparently not aware that one of the two buffers first constructed was made with taper bars to gradually contract the orifices on recoil, and to maintain an equal resistance; but this form was found to be less suited to the conditions of recoil of ordinary garrison carriages than the simple one on account of the higher pressure at the end of the recoil causing a jump of the front of the platform, and the buffer, which gave great resistance at the commencement of recoil, when the position of the gun over the front of the platform was most favourable to preserving the stability of the mounting, was adopted as being the most suitable. It must be remembered that the conditions of ordinary carriages and platforms were different from those associated with the Moncrieff and similar carriages, which were held securely from rising at the front ends. With regard to the theoretical line of argument, Mr. Barlow had justly remarked that "it appeared to him that Mr. Bousfield had treated the gun as being perfectly rigid, whereas, in fact, it was elastic." The Rev. James White had also said that "persons who taught mathematics were apt to forget that they were dealing with ideal conditions, and that practically men might make use of terms which might seem to teachers confused, but which did not necessarily imply a confusion of ideas on the part of persons using them," and that, "There was no doubt action and reaction were equal, but in the Paper it appeared to him that the subject had been dealt with entirely from the point of observation, and that the great laws of motion, especially the important law of action and reaction, were not touched by the question under discussion." These valuable remarks of gentlemen whose mathematical attainments were beyond suspicion, added to the equally important observations of a similar character by Mr. Cowper and Dr. Siemens, constituted in themselves a sufficient answer to Professor Unwin and Mr. Bousfield; but he would pursue the subject somewhat

Digitized by Google

farther as he felt it incumbent upon him, not only to answer the objections made, but to establish his views in a clearer light than was possible in the necessarily brief notice which the general character of the Paper permitted. Professor Unwin had stated that "the whole forward momentum given to the shot, to the powder charge, and to the air in front of the shot, must be equal to the whole of the backward momentum given to the gun, to the gun carriage, and to the whole mass of the air." Assuming for the moment that the ideal conditions upon which this statement was based correctly represented the actual conditions, Mr. Butter would still be justified in his attack upon the manner in which the formula had hitherto been constantly applied, for the air had always been omitted and generally only one-half the charge had been taken into account. But he further contended that it was incorrect to assume that action, without any limitation of conditions, must always expend itself in generating momenta, as generally understood, namely, the rate of motion of translation into the weight, and not including molecular motion. If this were true, action and reaction could not be equal under the conditions in which bodies were sometimes acted upon by a common force, such, for instance, as the varying conditions of their elasticity and of the amount of action converted into heat. Newton's law was so well expressed that all modern discoveries affecting the principle of the conservatism of energy served but to show its absolute truth; and when it was assumed that action, comprehended under the form of powder-pressure, set up between two bodies of whatever difference of weight, molecular and other conditions, must necessarily produce equality of momenta, which, in its applied sense, was but one out of several modes in which reaction might, and mostly did, manifest itself, he thought that statement must be regarded as being more opposed to Newton's law in its universal sense, including reactions of every kind, than was any statement which he had made. In point of fact, the formula of the equality of momenta (accepted as mathematically correct by Professor Unwin, but repudiated by Mr. Bousfield) could be true only when certain conditions existed, which conditions were purely theoretical. It was, nevertheless, invaluable for purposes of purely mathematical investigation, and in many cases where it was practically known the error could not be of importance. His position was this, that it had been, without qualification, wrongly applied to ascertain the highest velocity of recoil of the gun, or of the gun and carriage combined, and failed to give results in conformity with observed data. It would be well at this point to

Mr. Butter.

Digitized by Google

Mr. Butter. recall what the observed facts were. First, there could be no doubt that, with the same total amount of powder-pressure acting between the gun and the shot up to the time of the shot leaving the muzzle, and any unequal pressure acting afterwards, there was about one-third greater energy of recoil with pebble than with R. L. G. powder, the shot in each case having the same energy; secondly, that the times during which the two kinds of powder acted in the bore were about as 3 to 4 respectively; and thirdly, that while the equation of momenta was applied to obtain the highest velocity of recoil of guns fired with charges of R. L. G. powder, and gave results fairly correctly, the introduction into the formula of the empirical value $\sqrt{\frac{4}{3}}$ rendered it possible, in the absence of more accurate knowledge of the exact conditions, to obtain the highest velocity of the same guns fired with pebble powder, adding the full weight of the charge to that of the shot in each case to give the value of w. These facts, he thought, must be beyond dispute, since they were confirmed, no less by careful and repeated observations upon the direct effects of the discharges, than by the results of independent calculations from other observed data, such as the time waves in the pressure-curves of recoil, and from the areas of the curves. In dealing with the causes of these facts, he was aware that nothing could be definitely established except by more extended observation and experiment, and by mathematical deductions from data so obtained. It was nevertheless permissible to advance speculative theories based upon *à priori* reasoning, if only for the purpose of inciting more competent persons to direct attention to the subject, or of indicating the direction in which experimental research might be expected to realise the necessary data, and it was upon these grounds that he had brought forward the theory of the action of discharge. The practical value of the Paper was in no sense bound up with the theory, its whole scope being to show that from actual observations, the mathematical method generally in use for finding the velocity of recoil did not give correct results, without the introduction of some constant. The causes of the insufficiency of the mathematical formula alone to solve the problem were no doubt both complex and of an indeterminate character; they must at least include the following:—First, the mode of "action" of the exploded powder; second, the loss of energy in the development of heat; third, the effect of elasticity in the masses of the shot and gun with reference to the time occupied in compression and restitution; fourth, the effect of the gas-pressure acting upon both the shot and the gun after the former had left the bore; fifth, the resistance of

Digitized by Google

the atmosphere and of friction. The effect of the resistance of brakes, of the carriage moving up a slope against gravity, &c., which had been alluded to by several gentlemen, should not be included in finding the velocity of recoil; such velocity should be that of the gun and carriage moving as freely as possible in order to have the means of determining the total energy which the resistances of brakes, &c., had to meet in the length of recoil to which it was desirable to restrict the gun. The Paper being of an entirely practical character, but small attention had been paid to these causes as a whole, so little being known regarding them. The third was considered to be the one to which the least attention had been directed, and that which probably most affected the result, and hence it was embodied in the speculative theory which had, contrary to expectation, attracted the most attention. Had such a result been anticipated, much greater care and more elaboration would have been exercised upon it; as it was, he would endeavour to correct this omission, and in dealing with these causes, to show that the formula for the equality of momenta was, contrary to Professor Unwin's assumption, insufficient in itself to meet the case; the reasoning in itself would also prove that Mr. Bousfield's position was equally untenable, both these gentlemen having based their demonstrations upon the usual ideal conditions which would be shown to be different from what they most probably were in actual fact. In the first place the "action" of the powder-pressure did not exactly correspond with the pressure of impact, nor with that of steam or of compressed air; it would be found fully described in the "Researches on Explosives" alluded to in the Paper. The products of combustion consisted of two-thirds by weight of heavy liquid particles diffused, at first, in a finely divided state throughout the remaining one-third, which consisted of a highly elastic gas; the products of the first portions ignited were projected with enormous velocities along the lines of least resistance "through the interstices of the charge, or between the charge and the bore, and on meeting with any resistances their *vis viva* is reconverted into pressures," thus currents, or waves, of mingled *vis viva* and pressures were from the first set up. Unignited portions, no doubt, acquired a high momentum in the direction of the bore before ignition was completed, and continued the same action more or less, hence a succession of particles were hurled in waves against the base of the shot, and possibly in a less degree, as a whole, upon the gun; the result upon the shot was that "with rapidly burning, and in a less degree with the slower burning, powders, motion is communicated

Mr. Butter.

Digitized by Google

Mr. Butter. to the projectile by a series of impulses more or less violent." The reactions to a great extent contributed to equalise the effects upon the shot and the gun, but even when no abnormal violent wave-actions existed, the chronoscope pressures, as a whole, obtained by the motion of the shot, were generally 5 to 7 per cent. greater than those of the crusher-gauge which gave the pressure on the gun; and yet the maximum pressure on the gun invariably exceeded that upon the shot, at times to the extent of 15 per cent., which showed the complicated nature of the action. With regard to the second cause of variation, the loss of pressure, by the communication of heat to the bore of the gun and to the shot, was so great and rapid that while the full theoretical effect was nearly realised in the largest guns, the amount secured in the smallest was only about 50 per cent., and this was due in great measure to the loss of heat. Since the effect of this loss was so rapidly manifested in the pressures, it might well be regarded as possible, that it operated as an additional disturbing element in the action of the products of combustion upon the shot and the gun. Taking, then, into careful consideration these well authenticated facts alone, it would be seen that there existed no justification for the assumption that the mathematical expressions of either Professor Unwin, or of Mr. Bousfield, were strictly applicable, but that, on the contrary, his assertion that the question was, for the present, outside the range of strict mathematical investigation was fully proved. The third was more immediately connected with the theory he had ventured to advance. This Mr. Bousfield had attacked in very summary fashion, and Professor Unwin feared it might lead, if true, to the rewriting of mathematics; but he maintained it would, if accepted, lead perhaps to mathematicians using greater caution in the application of well-known laws, until they were convinced of the identity of the conditions of the problem under investigation with those upon which the laws were based. It would, he thought, be conceded that both these gentlemen had assumed, as the basis of their mathematical expressions, that the shot and the gun were to be regarded as heavy particles, that was, capable of communicating any change of pressure instantaneously to their respective masses, and of having their rate of motion affected instantaneously thereby, whereas his position was that they were to be regarded as elastic bodies in the nature of steel springs of great resisting power, but nevertheless subject to the same mode of action under the influence of high pressures suddenly applied, and requiring the lapse of an appreciable interval of time, proportioned in some degree to their masses, to convey the pressure

Digitized by Google

throughout the mass. It would thus be seen that the contention rested more upon physical conditions than upon mathematical laws. They claimed instantaneous effect from a given cause, he, a delayed effect, so far as motion of the whole mass was concerned. Grant his physical conditions to be true, his theory and the various terms he had used in formulating it would be perfectly clear and consistent with terms in common use in all text-books on dynamics, although it might not be regarded as in itself correct—in any case they could not fairly be judged from the mathematical point of view alone. It was curious that while, on the one hand, all persons devoted to physical research were convinced of the fact that instantaneous effects extending over large areas, from the operation of forces, was an impossibility, even the most rapidly acting, such as light and electricity, required some interval of time. Mathematicians still resented the introduction of time in connection with the transmission of pressures producing change of motion, mainly upon the supposition that it interfered with the equality of action and reaction, with which it had in reality nothing to do, although it might with equality of momenta in such cases as the discharge of a gun, which differed wholly from ordinary impact, in which, however different the interval of time might be to communicate motion to their respective centres of gravity, they would remain in contact until the action and reaction were completed, and thus would result in true equality of momenta; while in the case of the shot and the gun, if their elasticity were taken into account with reference to their enormous difference in mass, and the different intervals of time required to transmit suddenly applied pressures throughout them, so as to set up motion, it seemed to him clear, that the instant at which motion to the whole mass of the gun occurred, must be delayed beyond that at which the shot moved. In other words, the velocity at which the longitudinal vibrations travelled in the shot and the gun being regarded as nearly identical, it followed that they must traverse the shot in a much smaller interval of time than they did the gun. The resistance to motion in the small interval of time during which the powder-pressure rose to many tons per square inch, undoubtedly gave rise to a compression of the material of both shot and of gun to some extent, before either moved as a whole, that was with the acceptance of the conditions of elasticity and time before stated, and the wave of pressure was completed in the shot when it had only penetrated a short distance in the gun; after the shot had began to move, the generation of gas-pressure was so rapid that it continued to rise, and conse-

Mr. Butter.

Digitized by Google

Mr. Butter. quently still further to compress the material of the shot and the gun until the highest pressure was attained, at which point the shot had moved ½ inch with R. L. G., and 6 inches with pebble, powder. The use of the expression "overcoming inertia," to which so much objection had been made, was, when associated with the conditions of time and of elasticity, not therefore so unscientific as Mr. Bousfield asserted. Of course, the expression "overcoming inertia" could not, nor was it intended to, be confined to imparting motion to a body at rest, but would equally apply to one already in motion, the resistance under the same conditions to a change of motion being the same as would be opposed by a body at rest. This was essentially different from the definition of inertia given by Mr. Bousfield, who stated, "The overcoming inertia meant the setting up a certain velocity;" if this were so, then what should that resistance be called which bodies opposed to the setting up of any given rate of motion in very small spaces of time, and by virtue of which a 300-lbs. shot might, and did, oppose a resistance of 1,500 tons? Nor did his definition accord with that given in text-books on dynamics, for example, Weisbach stated, "If we raise a body slowly enough to be able to disregard its inertia." The idea conveyed here was the setting up of velocity without bringing inertia into action at all, it was when a force was applied to produce change of motion in a restricted interval of time that the resistance of inertia demanded consideration. The 300-lbs. shot lay in the bore perfectly free to move, except for a comparatively small amount of friction, and if a continuous pressure of no more than about 100 lbs. were applied to it for a sufficiently long interval it might ultimately attain to a velocity of 1,500 feet per second; but as this velocity has to be imparted in a very small interval of time, the pressure actually reached 1,500 tons, this pressure could only be reached by preventing the expansion of the powder gas, and this the shot did, although free to move with a pressure of only 100 lbs. Inertia therefore was that resistance associated with time which a body opposed to change of motion; and when the time was extremely small the property of elasticity and other phenomena were brought prominently into action, which was not the case when the time was unlimited. A pressure of 1,500 tons caused a compression of 0·066 inch in a cast-iron shot, and the energy requisite to produce this amount of compression was 10,225 foot-lbs.; from the moment of greatest compression this energy commenced to react upon the powder-pressure to increase the velocity of the shot, as in ordinary impact, while at the same time the powder-pressure acted as a

Digitized by Google

directly accelerating force, imparting velocity as it would do to an inelastic body; the increase of velocity due to the restitution alone, assuming the shot to be perfectly elastic, was 45 feet per second. From this it would be seen that there was good reason for the statement that the muzzle velocity was due to completed impact, and to the accelerating force of the powder-pressure. The same actions occurred in the gun, but, still keeping in view the element of time in the propagation of waves of pressure, both the setting up of motion and the total compression and restitution must necessarily, by reason of the greater mass of the gun, be delayed beyond the periods at which they took place in the shot; the result of this would be that restitution in the gun must, at least, take place with a resisting powder-pressure considerably less than that upon which the shot acted, and this in a greater degree in the case of R. L. G. powder, since pebble-powder maintained for a much longer interval its higher pressure, and also acted in the bore a longer time (4 to 3). The late Mr. R. Mallet, M. Inst. C.E., had a similar view in principle to this, in his work "On the Physical Conditions involved in the Construction of Artillery," when speaking of "the rate at which force itself is transmitted through the mass,"[1] he said, "were it possible to have a gun of sufficient thickness, therefore, the impulsive effect of the explosion might have reached its maximum and vanished altogether before the strain visited on the interior portions had been transmitted to the exterior. This cannot occur in practice, but in no case is the whole of the impulse transmitted equally through the whole thickness of the gun." It might well be the case that the experiments quoted as to the position of the shot when recoil commenced might not be considered conclusive, since they had not been confirmed by the requisite number and variety of experiments, which rendered other data given in the Paper more reliable; but if these were rejected altogether, his position, as would be seen by the foregoing argument, would be affected only in degree and not in principle; and in any case the fact that one-third greater energy of recoil resulted from pebble than from R. L. G. powder had to be accounted for. The fourth cause of variation from the mathematical conditions of impact was that which several gentlemen had shown themselves disposed to refer the whole of the difference in the energies developed by pebble and R. L. G. powder; of reliable data in regard to the action upon the gun of the discharged gases after the shot had left the bore, there were none; all

Mr. Butter.

[1] *Vide* p. 70.

Digitized by Google

Mr. Butter. conclusions in respect to it must therefore be of a purely s
lative character. Mr. White had shown by reference to va
experiments that it could not be so great as had been imagi
it must be borne in mind that this cause operated, although
less degree, in the case of R. L. G. as well as in that of pe
powder, so that to account for the difference of one-third in t
respective energies a much larger proportion than one-third of
energy of recoil of pebble powder must be due to the back pres
of the liberated gas, and considering how small, comparatively
what it had been in the bore, this was to begin with, and how rapi
by free expansion in the air, it would cease, it could scarcely
seriously maintained that the full difference was due to this c
alone, although he admitted it must have an important bea
upon it. It was needless to consider the effect of the resistance
friction and of air upon the shot and the gun respectively, as th
had been generally accepted. Looking then at the whole ques
from the point of view of the physical conditions which wo
appear to govern it, he thought no grounds existed for the co
dence with which Professor Unwin and Mr. Bousfield maintained
entire sufficiency of existing mathematical expressions to meet
case; and that there was ample justification for the introduction
some constant, to meet the unknown quantities, into existi
mathematical formulæ. He was not disposed to defend hims
from the charge of a misapplication of mathematical expressio
to any greater extent than he had done. That relating
"inertia" was the most serious, and no doubt arose on the part
his critics from not fully realising the conditions he had in vie
when he used the expression.

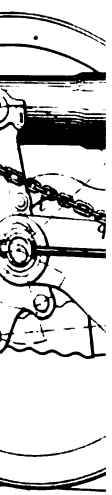


Fig. 4.

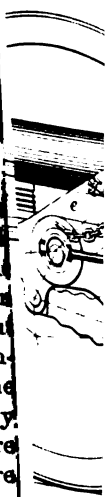


Fig. 5.

Correspondence.

Mr. Bashforth. Mr. F. BASHFORTH remarked that there could be no doubt th
great advantage would result from the introduction of some elast
material between the gun and carriage of field guns, provided th
invention were simple and not peculiarly liable to be damaged o
service. He thought a good result would have to be worked ou
by trial, because so little was known about the action of gun
powder. As to the kind of action of exploding powder on the
gun, he believed it was for the most part correctly treated by
Hutton, Didion, &c., in their accounts of the gun pendulum. There
could be no doubt that, if it were possible to apply a pressure
P—p to the breech of a gun at all times equal to pressure P of the
exploding powder on the base of the bore, less p the forward

Digitized by Google

Fig : 4.

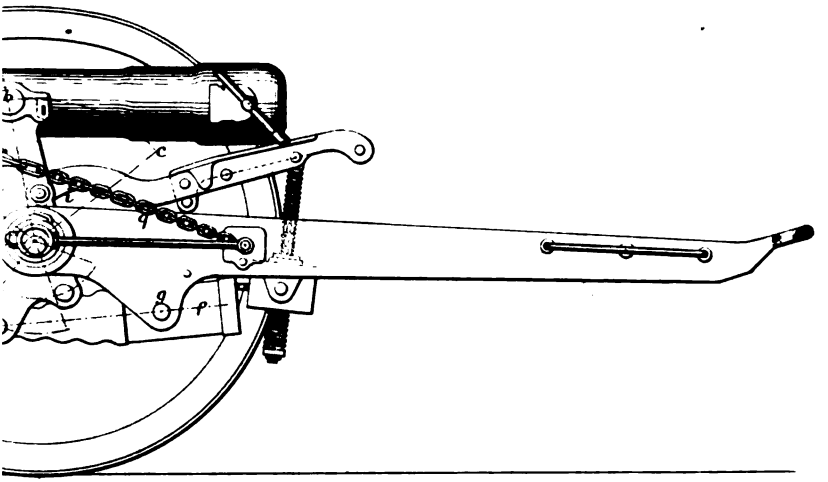
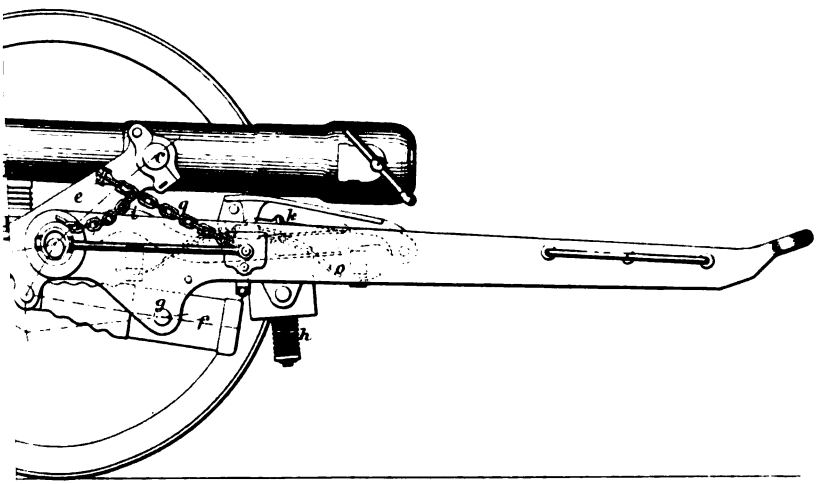
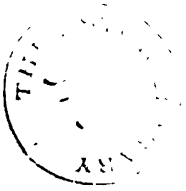


Fig : 5.



Digitized by Google



Digitized by Google

pressure of the studs, &c., the gun would be prevented from recoiling. Mr. Bashforth.

But next to nothing was known about the pressure of exploding powder in the bore of a gun. He could not, therefore, agree with the Author that Researches on Explosives had settled all questions relating to the action of powder-pressures on the projectile with a completeness that left nothing to be desired. So far as the "projectile" itself was concerned, that was found by measuring the initial velocity of the shot. But the long and costly series of experiments was undertaken with a view to discover the action of powder-pressure on the gun. And, so far as he could understand the results arrived at, there was an enormous variation in the pressures exerted by the exploding powder on the gun, even when the shot had the same muzzle velocity and was fired with the same charge from the same gun. The experiments appeared to point to the conclusion that powder fired under apparently like conditions was liable to enormous variations in the stress it threw upon the gun. He was, therefore, not surprised to find Sir W. Armstrong declaring (16th March, 1880) that "nothing, in fact, wants investigation so much as this powder question, and until we arrive at more definite conclusions we cannot hope to be altogether free from accident."[1] And this was said after the failure of one of his 100-ton guns, although its strength was far beyond what a normal pressure would demand. Of course the recoil of a field gun would depend upon the nature of the ground on which it was placed, and, when the gun was fired, there would be an impulse given to the carriage by the gun, and another by the ground. He had often recommended experiments to determine the law of recoil of the gun similar to those mentioned in the Paper, but in vain. The gun ought to be left as free as possible to recoil, and the curves ought to be traced with a diamond point. He was disposed to think this would give the best attainable law of pressure on the base of the bore when any gun was fired, unless an experimental gun could be constructed on Captain Morgan's plan, which would reduce the mass of the part set in motion, and so give the law of recoil better.

Mr. G. CANET was unable to agree with the Author's novel ideas on the recoil of guns, as they were contrary to mechanical principles and facts. If left unchallenged, the Author's theory might lead into error those who had to investigate the delicate problem of the recoil of guns. Mr. Canet.

[1] *Vide* Proceedings of the Royal Artillery Institution, vol. xi., p. 197.

Digitized by Google

Mr. Canet. The formula of the velocity of recoil, deduced from the equality of momenta, had never been right, as some factors had been left out of account; but as these factors were not generally of great importance at the beginning of the recoil, the velocity of recoil calculated by this formula was not very far from the truth. However, it must not be forgotten that this velocity was that of the gun and carriage when the projectile left the muzzle. It was not the same as regarded the maximum velocity of recoil; it was obvious that when the projectile had left the gun, the powder gases continued their action on the bottom of the bore till they were expanded to the atmospheric pressure, and the velocity of recoil increased more or less according to the resistances opposed to the motion of the gun. In order to design properly carriages strong enough for the work they had to perform, without more weight than was just required, it was important to understand thoroughly the action of the powder-pressure on the gun and carriage, which might be considered as part of the gun when there was no play on the trunnion-bearings. The Author seemed to think that inertia was such a special resistance that, on account of its great mass and the short time during which the pressure acted, "the gun was not directly obedient in its motion of recoil to the variations of powder-pressure, but stored up the total work of the pressures to be afterwards developed in one complete dynamic effort." Inertia was nothing of the kind. It was the resistance that a body at rest or in motion opposed to a change in its velocity, so that as long as the gun did not move there was no inertia to overcome, and at first the powder-pressure had only to overcome the ordinary resistances such as gravity, friction, &c. It followed that the recoil must begin nearly at the same moment as the shot moved, because as soon as the powder was ignited the pressure increased very rapidly to what was required to push the shot and the gun, as shown by the curves (Plate 2, Fig. 1). When a shot was deformed in the bore of a gun, it was not due to inertia, but to a pressure too great for the metal of the shot to withstand. This had been proved by some experiments made at Calais in 1872, to find the influence of the centre of gravity of common shells on the flight of projectiles; some lead had been run into the shells to bring them to weight, when it was found that the base of the shells was considerably set up by the firing. When sand was used instead of lead, the shells came out of the gun without injury. The inertia was the same in both cases, but the lead could not sustain the powder-pressures without expanding, and this deformed the cast iron of the shell. What

Digitized by Google

was then the action of powder in the bore of guns? The powder-pressure had not only to act on the masses of the projectile, gun, and carriage, but it had to overcome various resistances, viz., the forcing of the projectile through the rifling against the atmosphere, and the friction of the carriage on the slide, the gravity and the resistance of the brake. Let d and B be these variable resistances, and the following formula would give the velocity of recoil V of the gun and carriage when the projectile left the muzzle :— Mr. Canet.

$$V = \frac{\left(w + \frac{w'}{2}\right)}{W} v + f(d, B) \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

w and w^1 being the weights of the projectile and charge, W that of the gun and carriage, and v the velocity of the projectile when it left the muzzle, which was less than the initial velocity, because the powder gases acted also a certain time on the projectile when out of the gun. As the maximum velocity of recoil would depend so much on the resistance of the brake, it would be impossible to lay down a definite rule for all cases, but it would be something in the shape of formula (a), the coefficient half of w^1 being replaced by a variable one β depending on the nature of the powder.

He had seen some rounds fired with compressors wrongly set, when there was no recoil; it was obvious there was no velocity of recoil. In formula (a) $\frac{(w + \beta w^1) v}{W}$ would be equal to minus function (d, B) and therefore

$$V = O$$

while with the Author's formula V would always have the same value, which was impossible. So much being said for the theoretical part of the question, it remained to be shown that what he contended for was not contrary to facts. The Author had brought forward a certain number of experiments which he was afraid could not be entirely relied upon, on account of the very rough apparatus which had been used. An eminent officer of the French Marine Artillery, Colonel Sebert, had devised, to study the recoil of guns and the motion of projectiles, very ingenious apparatus, and he was certain the results of experiments carried on with that apparatus would leave no doubt as to the effect of powder-pressure on guns. The apparatus used by Colonel Sebert to find the law of recoil was very simple. It was called a

Digitized by Google

Mr. Canet. "velocimetre." It consisted of a steel riband attached to the carriage, and pulled with it when it recoiled; it had therefore the same motion as the carriage. Over this riband were placed, in a fixed position, a tuning-fork and a series of little electric markers, which were electro-magnets, the armature of which carried a pen. When the current passing through the electro-magnet was broken, the pen moved sideways. To the tuning-fork was also attached a pen, and it was kept electrically in vibration. It was used for measuring the time from the number of vibrations it made per second. The surface of the riband was blackened with lampblack, and the pens of the markers and tuning-fork rested on it. When the carriage recoiled, the pen of the vibrating tuning-fork drew a sinuous line on the riband, and the pens of the markers drew straight lines, till the current passing in each marker was broken, when the line deviated. These markers were made to register on the riband the moment the shot left the muzzle, and when it passed through a certain number of screens. The full size diagram on the riband was as shown in Fig. 4. Supposing the tuning-fork vibrated one thousand times in a second, the carriage moved from *a* to *b* in one-thousandth of a second; it was therefore easy to deduce the velocities of recoil at any point; *c d*, *e f*, *g h* would be the lengths the carriage had recoiled when the projectile left the muzzle, and when it passed through the screens, and the time would be given by the number of vibrations of the tuning-fork. By a special contrivance the markers were made to act at the beginning of the recoil in order to be able to measure the time lost in the moving of the pens, time which had to be taken into account. He had selected a few amongst

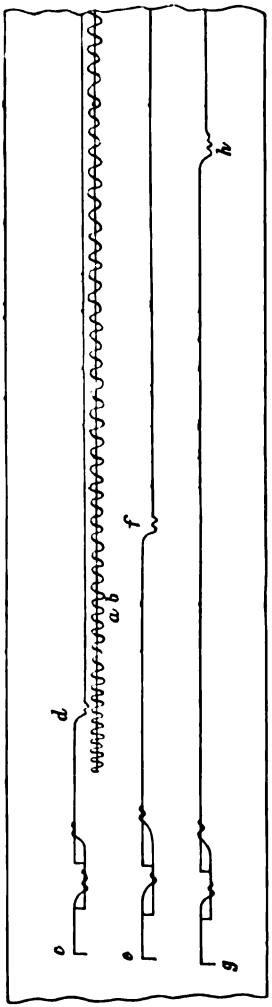


Fig. 4.

Digitized by Google

the numerous experiments carried out by Colonel Sebert; they showed the results obtained with a 24-centimetre (9½ inch) gun, weighing 15½ tons, mounted on a hydraulic carriage weighing 19 cwt. Mr. Canet.

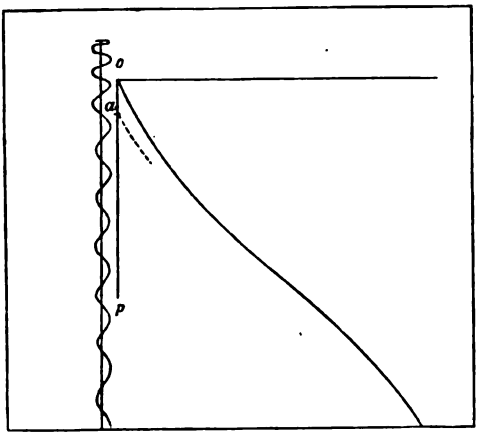
Date of Experiments.	Weight of Projectile.	Weight of Charge.	Initial Velocity of Projectile.	Velocity of Recoil when the Shot left the Muzzle.		Velocity of Recoil. Maximum Measured.	Length of Recoil.
				Measured.	Calculated from Formula (*a*).		
1878.	Lbs.	Lbs.	Feet-sec.	Feet-sec.	Feet-sec.	Feet-sec.	Inches.
17 August .	315·0	61·729	1,494	13·60	14·04	16·84	38·9
17 „ .	315·1	„	1,490	13·70	14·00	14·96	24·1
6 June .	315·9	„	1,477	13·45	13·91	14·44	15·6
28 „ .	317·5	52·911	1,354	12·22	12·65	15·62	32·4
28 „ .	316·8	„	1,338	12·27	12·47	15·55	31·9
6 „ .	317·9	„	1,370	12·07	12·81	13·79	38·0
17 August .	316·8	44·092	1,222	10·68	11·23	11·75	16·1
17 „ .	314·2	„	1,217	10·95	11·11	13·52	27·8
29 June .	317·4	„	1,220	10·84	11·24	13·91	28·2
29 „ .	317·5	35·274	1,057	9·42	9·62	11·56	24·3
29 „ .	317·5	„	1,059	9·34	9·64	11·67	24·2
29 „ .	316·8	„	1,068	9·50	9·70	11·75	44·9
29 „ .	316·8	26·455	892	7·63	8·00	9·33	20·1
29 „ .	317·5	17·637	689	5·72	6·11	6·69	22·6

The hydraulic compressors had valves loaded with springs. He had calculated from formula (*a*) the velocity of recoil when the projectile left the muzzle, but he could not take into account $f(d, B)$ as that function was not known. He should, however, expect when there was a powerful brake, that the influence of d was less than that of B, so that V calculated from (*a*) must be too great. He should anticipate the reverse when there was no brake, or when a Woolwich buffer was used, as it did not give any resistance before the carriage had recoiled a certain distance. It would be seen from the Table that it was impossible to give a formula to represent the maximum velocity of recoil, as it varied according to the setting of the compressor and the quantity of air that might have got into the hydraulic cylinders. When there was no air in the cylinders the maximum velocity decreased as the recoils got shorter. Colonel Sebert found that with the 61·73 lbs. charge the time of travel of the projectile through the bore was 0·012 second, while the velocity of the carriage increased during 0·030 second. When there was no brake it increased during 0·041 second. In that case the carriage had recoiled 1·2 inch when the shot left the muzzle, and 7·9 inches when the carriage had its greatest velocity of recoil; the projectile

Digitized by Google

Mr. Canet. was then 16 yards off the muzzle. To prove that the recoil began as soon as the projectile moved, Colonel Sebert used an "accelerograph," which consisted of a plunger moving in a plug screwed

FIG. 5.



into the walls of the gun over the chamber, like a vent-piece. This plunger, which had a certain weight, carried on its top a flat vertical surface blackened with lampblack. The plunger was acted on by the powder-gases exactly like the shot. In front of the flat surface was a guide, along which a pen could be drawn by a spring as soon as it was released by the recoil of the gun. The powder-pressure caused the plunger to be shot up, and if the pen did not move, the line drawn by the pen on the blackened surface would be parallel to the axis of the plunger; but as soon as the recoil began the pen moved, say to the right, drawing a curved line on the surface of the accelerograph. It would be seen from Fig. 5, which was full size, that this curve commenced at the starting-point of the pen; this showed conclusively that the recoil of the gun began as soon as the plunger; or, in other words, as soon as the shot moved. Should it not be so the curve would begin on a point a of the vertical line $o\,p$, when the plunger would have been shot up of the quantity $o\,a$.

As to the elastic field-carriage proposed by the Author, it afforded him great pleasure to put on record that a similar carriage was designed nearly three years ago by Mr. J. Vavasseur, M. Inst. C.E., to whom artillerists were indebted for many other valuable inventions extensively used. The description given by the Author seemed sufficient to explain the Vavasseur field-carriage. Plate 5,

Digitized by Google

Mr. Canet. Fig. 1 showed a longitudinal section through the axis of the hydraulic compressor, the gun being in its firing position. The piston of the hydraulic compressor was pierced with two holes; in its central part was inserted a circular valve with holes corresponding with those of the piston. This valve had two projecting studs, which entered special grooves cut in the cylinder. During recoil the valve turned round gradually, closing the orifices. The dimensions of the holes were such that the resistance of the compressor was uniform during recoil. Fig. 4 showed the carriage ready to change its position during action, and Fig. 5 showed the gun in its travelling position; all sudden concussions were prevented, as the gun rested on springs *o* and buffer *p*. A greater portion of the weight of the gun was brought on the limber. No doubt if it were desired to increase much the velocity of field guns, the carriages now in service would not stand the work, and it would be necessary to use a carriage similar to that proposed by Mr. Vavasseur or the Author.

Mr. Davey. Mr. Henry Davey observed that the Institution was indebted to the Author for submitting the forces and strains of recoil to direct experiment, the only satisfactory way of dealing with the problem. The Author first gave the formula derived from the accepted equation for the equality of momenta after impact,

$$\left(V = \frac{v\,w}{W}\right),$$

for ascertaining the maximum velocity of recoil. He then proceeded to state certain propositions as being usually accepted as true; viz., that the force of recoil could not exceed the maximum powder-pressure on the bottom of the bore, even in the case of holding the gun rigidly immovable; and that, while slow-burning powders might increase the length of recoil, the intensity was less in the same proportion as the powder-pressure inside the bore. But he also said that these views depended for their truth upon directly opposite conceptions of the nature of recoil. Now there was certainly ambiguity in the enunciation of the propositions. First, the term force of recoil was evidently intended to mean the same thing as intensity in the second proposition. If the terms were, as Mr. Davey believed they were, intended to mean the force resisted by the gun in the line of fire, when held perfectly immovable, it was difficult to see that the propositions were not true. If the gun were immovable, it was incapable of accumulating energy, because it could not acquire velocity. As regarded the application of the equation for the equality of momenta in deter-

Digitized by Google

Mr. Davey. mining recoil, he thought the Author was right in questioning its accuracy. The impact of the explosion took place in the breach of the gun, and its first effect was to compress the metal forming the breech, next to set up a high tension throughout the gun; and should the motion of the gun commence before the shot had left the bore, then the effect of the recoil would be augmented by direct powder-pressure acting between two moving bodies. Evidently, from the electric experiment alluded to by the Author, the gun did begin to move before the shot left the muzzle; and it would be interesting to have more conclusive proof of this, because he did not think the observations by so-called instantaneous photography could be relied on. He considered the Author was wrong in saying that the energy of recoil was due to the sudden liberation of stored-up work, rather than the direct action of powder-pressure, since the latter had ceased before motion in the gun was set up. It appeared to Mr. Davey that the reason why the energy of recoil with slow-burning powder was greater than that with quick-burning powder was that, in the former case at all events, the powder-pressure had not ceased before motion in the gun was set up. The observed increase in the length of recoil, consequent on the use of pebble powder as compared with R. L. G. powder, might be accounted for partially by the fact that with the pebble powder the maximum velocity of recoil was attained later than in the other case, and as a longer space was passed over in accumulating the energy, the sum of the spaces passed over during the accumulation and dispersion must necessarily be longer. In other words, the path of recoil might be divided into two parts: first, that traversed whilst the velocity of recoil was increasing; and the other, that traversed in bringing the gun to rest. The slower the powder was burned the longer would be the first part, and therefore the longer the whole. The Author had given no indication of the methods employed in eliminating the errors incidental to the mode of carrying out the experiments; such an error, for instance, as that due to the difference between the friction of rest and of motion. The hydraulic buffer appeared to be an excellent method of reducing the force which would be otherwise brought to bear on the carriage, by causing the inertia to be overcome gradually instead of suddenly.

Prof. Greenhill. Professor A. G. GREENHILL observed that the facts and the results of the experiments, brought forward by the Author in the Paper, showed the insufficiency of the ordinary data for calculating the velocity of recoil and the strains due to its action. Although at first sight it might appear that the experiments exhibited a

Digitized by Google

violation of the third law of motion, "action and reaction are equal and opposite," yet this apparent discrepancy was useful in directing attention to phenomena which had hitherto been considered insignificant and unimportant in comparison with those which had usually been taken into account. With the ordinary hypotheses employed, the gun and carriage were considered to form one rigid body, and the recoil was supposed to take place as if the gun were fired from a smooth horizontal platform. On these hypotheses the momentum of recoil was equal to the momentum of the shot at the instant the shot was escaping from the muzzle, and the centre of gravity of the gun and shot had not moved up to that moment. But the old experiments with the ballistic pendulum, performed by Dr. Hutton, proved that the momentum of the recoil was greater than the momentum of the shot, and the discrepancy must be accounted for principally in the motion imparted to the air at the muzzle by the flash of the discharge of powder. When it was considered how far the flash would extend, particularly with slow-burning powder, and that the weight of 13 cubic feet of air was 1 lb., it would easily be seen that it was no exaggeration to suppose that an amount of momentum might be communicated to the air equivalent to from one-third to one-half the momentum of the shot, so that the velocity of recoil was from one-third to one-half time greater than it would be if calculated from the principle of the equality for momenta of the gun and the shot. The experiments adduced by the Author proved, however, that to obtain a true idea of the nature of recoil in its action on the gun-carriage, and in the means which must be employed to control the recoil, the old hypotheses of perfect rigidity must be abandoned. The Author had spoken of the elastic yielding of the shot; but this effect he should consider unimportant compared with the elastic yielding of the gun, in consequence of the greater relative length of the gun. It was this elastic yielding which made time such an important element in overcoming inertia. To take the simplest instance, reversing the conditions of the discharge of a gun, and imagining two elastic cylinders of equal cross-section to impinge directly, then, on the hypothesis of perfect elasticity, the shorter cylinder (which must be taken to represent the shot) rebounded without vibration, and the time of impact was the time a longitudinal vibration took to traverse twice the length of the shorter cylinder; while in the longer cylinder (representing the gun) a wave twice the length of the shorter cylinder was propagated backwards and forwards, causing a worm-like progression of the longer cylinder. Of course in practice the imper-

Prof. Greenhill.

Digitized by Google

Prof. Greenhill

fect elasticity of the materials speedily destroyed this wave-action, leaving eventually, after a certain time, the resultant momentum as calculated on the hypothesis of perfect rigidity. This gradual destruction of vibration was beautifully exhibited in the records produced by the Author. To measure the recoil accurately the endeavour should be made to exaggerate its amount. The model produced by Sir Frederick Bramwell would doubtless afford interesting results in this way. . Another method of increasing the recoil and measuring its amount would be to suspend the gun alone, without any carriage, by two equal parallel vertical chains 6 or 7 feet long, and then the gun after firing would recoil parallel to itself, and the velocity of recoil would be eight times the square root of the height ascended in feet. If the gun was free to revolve in the collars by which it was suspended, then the rotation communicated to the gun, in consequence of the rifling, could be measured and would afford additional interesting results. A gun freely suspended in this manner, firing blank charges, would give better indications of the effect of the discharge of the powder in the air than a gun fired from the ordinary carriage, when a certain amount of friction had to be overcome before any motion would take place.

Prof. Jenkin.

Professor FLEEMING JENKIN observed that the Author had brought forward a curious fact, viz., the inequality of recoil observed when different powders were employed to give one and the same velocity to shot of a given weight. The only explanation which occurred to him as possible was, that the velocity of the products of combustion issuing from the gun must be very different in the two cases, although the velocity of the shot was the same. This at least would be a *vera causa* sufficient to account for some difference in the recoil. The data given in the Paper were insufficient to show whether the cause now suggested would produce the full effect described.

The explanation suggested by the Author appeared quite inconsistent with the well-established and fundamental laws of applied mechanics. The equality of momenta in opposite directions was a principle too well established by reason and experiment to be overthrown by any apparent contradiction; it was, indeed, obvious that the Author was not fully conversant with kinetics; this was shown in many places by the language employed. Thus it was stated: "Recoil, then, is due to a purely dynamic force, the resultant of the sum of all the powder-pressures." Professor Jenkin was not aware that there were two kinds of force, one dynamic and the other of some other nature; nor could he conceive how the

Digitized by Google

summation of all the powder pressures was meant to be effected. The Author was also greatly mistaken in supposing that by lengthening the bore of the gun the work of recoil would be made more and more nearly equal to the energy acquired by the shot. Prof. Jenkin.

Mr. LONGRIDGE said he had considerable difficulty in following the Author in his reasoning on the nature of recoil, owing to his apparently vague ideas respecting the forces and their action. In the first place, the Author took exception to the simple formula, as he termed it, of the equality of moments $V W = v w$. Now, as this formula was the expression of a universal law, it could be only to its application that exception could properly be taken. The fact was that the work done by the force, *i.e.*, the powder-pressure, was not simply moving the shot and the gun. There was the compression of the air and its displacement, the friction of the gases through the tube of the gun, the friction of the rifled projectile and of the gun-carriage, the extension of the body of the gun between the breech end and the trunnions, and other work done, all of which ought to be taken into account in a strict consideration of the question, and it was easy to see how at any rate some of them would be affected by the greater or less sudden application of the force arising from the use of quick or slow-burning powder. As an instance of the vagueness of expression above alluded to, the Author said, "It is stated that the force of recoil cannot exceed the maximum powder-pressure." What was meant by the force of recoil? Recoil was an effect produced by a force, and that force was purely and simply the powder-pressure itself. No one conversant with mechanics could maintain that the amount of recoil was dependent upon the maximum powder-pressure. If the amount of recoil were measured by the weight moved, and its attendant resistances multiplied into the distance moved, which was the only true measure, then it was evident that this distance must depend upon the velocity imparted to the gun; and this velocity did not depend on the maximum pressure applied, but was represented by the integral of the pressure at any moment into the time of its action; it was, in fact, $\int p\,dt$, when p varied from instant to instant. It was, therefore, easy to see that with a slow-burning powder this integral might be much larger than with a quick-burning powder, although the value of p at some particular instant of time might be much larger in the latter than in the former. An analysis of the pressure and time-curves taken by the chronoscope would show this conclusively. In the next place, the Author said that the energy imparted to the Mr. Longridge.

Digitized by Google

Mr. Longridge. shot was due to two actions, "the one being of the nature of completed pressure of impact, and the other, and by far the larger, a directly accelerating force." Now impact and pressure were one and the same thing, impact being simply a pressure of short duration applied very rapidly. It was as much an accelerating force as any other pressure. The powder-pressure began at zero, and were it not for the frictional resistance of the shot, and in a very minute degree from its elasticity, the motion of the shot would begin at the very same moment as the application of the pressure; but in reality the pressure must accumulate till it was equal to the resistance, and then motion began, and the force, like all other continually applied forces, accelerated the velocity of motion. It was the same with the gun. As soon as the pressure had accumulated so as to balance the resistance of the gun and its carriage, motion of the latter commenced, and if it was ascertained, by photography and electricity, that this motion only began when the shot was clear of the gun in the first instance, and when it was within 2 inches of the muzzle in the latter, it only showed that either the means of observation were imperfect, or that the pressure did not balance the resistances till the shot had attained these positions. If the gun really did not move till the shot was clear of the muzzle, it was difficult to imagine why it should move at all, except from the reaction of the escaping gases against the atmosphere. If when the shot left the muzzle the gun had not moved, it could only be because the work done on it had not exceeded the resistance. How then, apart from the reaction of the escaping gases, could motion take place afterwards? The Author spoke of the "energy of recoil . . . . due to the sudden liberation of stored-up work." How was this possible? He seemed to think it was stored up in the elasticity of the gun. Now this elasticity would be a force expended in stretching the gun between the breech and the trunnions, and this would be a force acting between two points of the same body in opposite directions. How could this give motion to the whole body? The Author contended that during the time the pressure was giving motion to the shot "it can only complete the wave of pressure in a mass one hundred and thirty-four times greater." That "this wave of pressure exhausts its action upon the elasticity of the mass of the gun, inducing a high degree of tension longitudinally; and . . . that the reaction of elasticity takes place in the absence of any opposing gas pressure, and in this respect resembles the pressure of impact of an inelastic body;" and a little further on, "the gun is not

Digitized by Google

directly obedient in its motion of recoil to the variations of powder-pressure, but stores up the total work of the pressures to be afterwards developed in one complete dynamic effort." According to this idea a body could be at rest in space, some portion of which was in a state of internal strain, the restoration of which internal strain to its normal state of equilibrium produced an accelerating motion through space of the whole body. Was this possible? If not, to what could be attributed the recoil which took place after the shot had left the gun? It would appear to be due simply to the reaction of the escaping gases. But, in fact, all the resistance to motion had at this time been balanced, and the gun and carriage were then perfectly free to move (if indeed they had not already moved, though such motion might not have been detected), and the unbalanced reaction of the gases during their escape had then only to move the unresisting gun and carriage, which it would probably do, through a much greater distance than the actual distance of recoil, were it not for the continued action of the frictional resistance of the gun-carriage. Mr. Longridge.

Although differing entirely from the Author's views as to the action of the forces which produced recoil, Mr. Longridge considered great credit was due to the Author for his advocacy of an elastic medium, or the resistance of hydraulic flow for the purpose of absorbing a portion of the force which otherwise would be transmitted direct to the gun and carriage, and have to be counteracted by dead weight. By this system a large amount of force was absorbed in generating internal resistances, which did not tend to displace the body in space, and this was an immense advantage if the apparatus employed could be made so as not to impede the working of the gun, and not be subject to derangement or destruction, and the Author's efforts in this direction appeared to have been well conceived and efficiently carried into practice.

In a Paper read many years ago Mr. Longridge pointed out and advocated the introduction of an elastic medium between the gun and the gun-carriage,[1] and he was glad to find that the subject was now attracting serious attention, and was being ably carried into practical effect by the Author of the present Paper.

Mr. MacAvoy observed that any system of construction which would enable the force of recoil to be spread over a certain space, instead of allowing it to act suddenly, like a blow, would bring much less strain on the carriage, and would therefore enable its weight to be reduced. Now, as the Author's invention of the Mr. MacAvoy.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 314.

Digitized by Google

Mr. MacAvoy. hydraulic buffer placed in the hands of engineers the means of depriving a heavy body in motion of its momentum, however great it might be, in a definite space and according to any desired law, there could be no doubt of its suitability to the purpose under consideration; but it was obvious that its value, compared with any other system, could only be determined by trial. With regard to the theoretical points dealt with in the Paper, those relating to the momentum of the gun and the propagation of the powder-pressure through its mass seemed to demand the chief attention. At first sight the deductions from the experiments appeared to be at variance with the usually accepted theory on impact. The early experiments on impact confirmed the laws deduced from the theoretical considerations; but the masses acted upon were generally such as to enable them to be regarded as heavy particles, and the pressures of impact on each body could then be taken as acting instantaneously throughout the mass. But in a heavy gun, the mass acted upon was so enormous that it seemed quite in accordance with the known action of other physical forces to assume that pressure, instead of acting suddenly on the whole mass, was propagated through it in a wave whose duration occupied a definite interval of time, and the motion of the whole mass would not then be apparent until the wave was completed. Now the time occupied by the shot in passing along the gun was a very small interval, and if this were about equal to that taken to complete the pressure-wave through the gun's mass, the interval said to elapse between the commencement of motion of the shot and that of the gun would, he thought, be satisfactorily accounted for.

In considering the momentum generated by the action of the powder, it was difficult to take any other view than that the total in each direction must be equal; for the pressures at any instant of time during the action must be equal and opposite, and if these pressures were conceived as acting on two masses perfectly free to move, as in the case of direct impact of two heavy particles moving freely in space, the effect would, no doubt, be strictly in accordance with theory; but when these pressures acted as they did in the bore of a gun, it seemed scarcely justifiable to assume it as a fact that the momentum imparted to the shot would be precisely equal to that imparted to the gun, seeing that the momentum generated by the powder in the direction of the shot might not be wholly expended on the shot, but that part of it might be expended in a manner which had not yet been taken into account.

The employment of quick-burning powder might be looked upon as producing, by its rapid conversion into gas, an effect approxi-

Digitized by Google

mating much more nearly to that of impact than would be the case when slow-burning powder was employed; and the effects in the latter case, although bearing a definite relation to those in the former, might still not be precisely equal as regarded the shot and gun. The results of the experiments referred to in the Paper appeared to confirm this. Mr. MacAvoy.

Whatever might be the theoretical conclusions on a question of this kind, it was evident that the facts of the case could only be determined by experiment; and supposing that the experiments already made on the motions of the gun and shot had been conducted in such a way as to leave no possible doubt of the accuracy of the results, then, if the usually accepted theoretical deductions did not agree with them, the only conclusion that could be come to was, either that the theory was wrong or that the whole of the conditions involved in the problem had not been taken into consideration. The latter was, in his opinion, the most advisable one to adopt. The object in view would then be to discover the whole of the conditions involved, and their respective values, so as to obtain a complete solution of the problem. The full consideration of so complicated a mechanical problem could not be done hurriedly. Much time must necessarily be occupied in the discussion of every point.

Dr. Pole thought it might be useful to state the manner in which recoil could be calculated according to the ordinary laws of mechanics, which it scarcely seemed necessary to depart from. Dr. Pole.

If a force f was applied during a very small period of time dt, to a body free to move, whose mass = m, it would give it a certain increment of velocity determined by the equation $mdv = fdt$. Let then ϕ represent the elastic force of the powder per square foot, acting against the shot, and a = area of bore, then the force urging the shot forward = $a\phi$. But from this had to be deducted the pressure of the atmosphere, which call ah; the force necessary to produce rotation, and the friction of the shot and gas-check. The two latter might be combined in one symbol = k. Then the effective force applied to move the shot = $a\phi - ah - k$.

Let w represent the weight of the shot, then $\frac{w}{g} = m$, and $\frac{w}{g}\,dv = (a\phi - ah - k)\,dt$. If t was the time elapsing from the starting of the shot till its exit from the muzzle, then (neglecting the resistance of the air)

$$\left.\begin{matrix}\text{Muzzle velocity}\\ \text{of shot}\end{matrix}\right\} = v = \frac{g}{w}a\int_0^t \phi\,dt - \frac{g}{w}(ah + k)t \quad . \quad . \quad . \quad (1.)$$

ϕ being expressed as a function of t.

Digitized by Google

Dr. Pole. Now, as the same forces acted during the same time in an opposite direction against the bottom of the barrel, it was only necessary to substitute for w in the above equation the quantity W, representing the weight of the gun, plus such parts of the carriage as moved with it, to give

$$\left.\begin{array}{l}\text{Velocity of recoil due}\\ \text{to the action against}\\ \text{the shot}\end{array}\right\} = \frac{g}{W}\, a \int_o^t \phi\, dt - \frac{g}{W}\,(a\,h + k)\,t.$$

But this was not all: not only the shot, but also the charge, which was of considerable weight, had to be set in forward motion, and according to the often-cited law of Newton, whatever force was necessary to produce this motion must react against the end of the barrel, and would consequently aid the recoil. Let this force be represented by γ, acting through a time τ; then the increase of velocity of recoil due to it would be $= \frac{g}{W}\,\gamma\,\tau$.

During the time that the shot was travelling along the barrel, the motion of the charge increased with it, and the mean velocity of the latter might be assumed to be half that of the shot. But as soon as the shot left the muzzle the imprisoned gases, being in a state of very high elasticity, flashed out into the atmosphere with great force, and with greatly increased velocity. Let the velocity of exit of the gases at the muzzle be represented by v_1, and let the mean velocity of the charge at that moment be assumed $= \frac{1}{2}\,v_1$. If then c = weight of charge, the quantity $\gamma\,\tau$ would be equal to $\frac{c}{2\,g}\,v_1$; and the increment of recoil $= \frac{g}{W} \times \frac{c}{2\,g}\,v_1$. Hence, finally,

$$\text{Total velocity of recoil} = V = \frac{g}{W}\left\{ a \int_o^t \phi\, dt - (ah + k)\,t + \frac{c}{2\,g}\,v_1 \right\} \quad \text{(II.)}^1$$

An example of the practical application of these formulæ might be taken from the data furnished for the 10-inch gun, with pebble powder, in Messrs. Noble and Abel's Paper already cited. The quantities were w = 300 lbs.; c = 70 lbs.; a = 0·545 square foot;

---

[1] If the velocity of exit of the gases were taken the same as the muzzle velocity of the shot, *i.e.* $v_1 = v$, a comparison of equations I. and II. would make

$$\frac{V}{v} = \frac{w + \frac{1}{2}\,c}{W}.$$

This was the ordinary rule; but it evidently gave the recoil too small, as it neglected the large further impulse given to the gases after the shot was out of the way.

Digitized by Google

h = 2,116 lbs. per square foot. The total time t, of travel of the shot in the barrel was $\frac{1}{80}$ of a second. As to the integral $\int \phi\, dt$, there was a difficulty in giving any general algebraical expression for it with reasonable simplicity, on account of the exceedingly complicated mode of variation of the powder-pressure; but it could be calculated numerically, in its definite form, from Table X. and Plates 19 and 20. The value came out, in lbs. × seconds, for 1 square foot area = 26,660. In regard to k, the first element, namely the force necessary to give the shot rotation, might be easily calculated; for, making r = radius of shot, and n = number of rotations per second, then, by the ordinary rule founded on the moment of inertia,

Dr. Pole.

$$\text{Work of rotation} = \frac{w}{g}\, \pi^2\, n^2\, r^2,$$

and the mean force acting on the base of the shot to produce this, with a final twist of one turn in 40 calibres = 3,400 lbs. The friction of the shot depended on the practical arrangements adopted, but it might be calculated approximately by aid of the principles laid down in Captain Noble's Paper in the "Philosophical Magazine."[1] For the twist there given, with a 300-lb. shot, it might be estimated at about 9,000 lbs. Hence k = 12,400.

Applying these quantities in the first place to equation I., the muzzle velocity of the shot came out = 1,540 feet per second, the actual measured velocity being 1,527 feet.

The calculation might be effected by another mode. If s represented the space passed through by the shot before quitting the muzzle, then, according to the law of *vis viva*,

$$v^2 = \frac{2g}{w}\left\{ a \int_0^s \phi\, ds - (ah + k)\, s \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

ϕ being expressed in terms of the space and not of the time. This integral might be also calculated numerically from Noble and Abel's Paper, and the result was

$$v = 1{,}534 \text{ feet per second.}$$

The correspondence of these estimations, in a case where the whole action occupied only $\frac{1}{80}$ of a second, appeared to justify the modes of calculation used.

To work out equation II. it was necessary to find the value of

[1] March, 1873. Vol. xlv., fourth series, p. 204.

Digitized by Google

Dr. Pole. the quantity v_1, *i.e.* the velocity with which the gases would rush into the atmosphere after the shot was gone. This might be estimated according to the usual laws of gaseous motion, knowing the pressure and density, which were to be found from Noble and Abel's data. The determination could not be very precise for various reasons; but it appeared probable that the velocity of exit might amount to three times the muzzle velocity of the shot, or say 4,600 feet per second. Using this quantity, equation II. became

$$V = \frac{626{,}000.}{W}$$

To complete the determination it was necessary to know the weight of the portion of the carriage which recoiled along with the gun; this was not given, and it might vary considerably according to the material and design of carriage used. For the gun alone, weighing 18 tons, the velocity of the recoil would come out 15·5 feet per second; if the recoiling portion of the carriage were put at say one-sixth additional, making W = 21 tons, then

$$V = 13{\cdot}3 \text{ feet per second,}$$

which would probably not be far from the actual value.

In Fig. 2 Mr. Butter had given three curves of recoil of the 10-inch gun with pebble powder, which showed a velocity, maintained through some distance, of about 14 feet per second; but as no particulars were given of the weight of shot or charge, or of the recoiling portion of the carriage, it was not possible to compare this with the calculation; and moreover, it was not professed that the apparatus was very accurate.

If the assumption that $v_1 = 3\,v$, were taken as generally applicable, the following simple formula would result, and probably this might be adopted in the absence of a better one.

$$\text{Velocity of recoil} = \text{vel. of shot} \times \frac{w + \frac{3}{2}c}{W}.$$

There were some other points of interest that might be mentioned.

The *work* stored in the forward motion of the shot was, according to the ordinary rule,

$$u = \frac{w}{2g} v^2 = 10{,}860{,}000 \text{ foot-lbs.}$$

Digitized by Google

Dr. Pole.

That stored in the recoil of the gun and carriage was (W being taken as 21 tons)—

$$V = \frac{W V^2}{2 g} = 129{,}000 \text{ foot-lbs.}$$

It was also interesting to inquire what amount of motion would be given to the gun, by the recoil, during the time the shot was travelling along the barrel. While the shot was moving forward, the gun (assuming it to be of perfectly rigid material) moved slightly backwards, so that if s and S represented the space moved over by each respectively, $s + S$ would be = the total travel in the barrel. The space S was somewhat difficult to determine; but it might be approximated to as follows.

Let V_o express the velocity of recoil of the gun, the instant before the shot left the muzzle, and let F = the mean pressure on the base of the barrel during the whole travel. Then

$$F S = \frac{W}{2 g} V_o^2.$$

Estimating the quantities F and V_o by approximate practical methods, the quantity S came out

$$= 0{\cdot}071 \text{ foot.}$$

So that supposing the total path of the shot in the barrel to be 10 feet, the shot really moved 9·929 feet forward, and the gun 0·071 foot backward. This very small recoil might easily be overlooked if not very carefully watched for, and it was possible it might be diminished, as Mr. Butter had suggested, by the temporary storing of work in the elasticity of the material.

A summary of the various amounts of work in this example might be added:—

	Foot-tons.
Work applied in giving effective propulsion to the shot .	4,890
In overcoming the pressure of the atmosphere against it.	5
In giving it rotation	15
In overcoming its friction against the barrel	40
In giving recoil to the gun and its accompanying part of the carriage	58
	5,008

This, however, did not include the work expended in giving motion to the products of the charge, which was a very large addition, and might be roughly estimated at 3,400 foot-tons.

The total work here developed by the powder would therefore be = 8,400 foot-tons, or 120 foot-tons per lb. of charge, equal to about one-fourth the total theoretical power of the powder.

Digitized by Google

Mr. Butter. Mr. BUTTER, in reply to the correspondence, observed that the discussion had been useful in proving that the majority of mathematicians had given little attention to the action of the forces producing recoil, and so far justified the production of his Paper, which had also been useful in drawing into one focus various facts and observations bearing upon the subject. No doubt the adverse criticism of most of the mathematicians was due to their having made no effort to judge his expressions and deductions from his point of view of the conditions of the problem, and they had attacked his statements on the basis of their own ideal conditions; whereas, if he were wrong, it would be in the enunciation of his conditions, and these had mostly passed unnoticed, except by Professor Greenhill and Mr. MacAvoy, who, in their observations, had fully realised them, and had given due value to the effect of the gradual propagation of pressure through masses, upon the time at which motion of the whole mass was effected, and this was the basis of all his deductions. Mr. Bashforth's proposition of preventing recoil by opposing a pressure at the breech of a gun equal to that of the maximum powder-pressure on the bottom of the bore was no doubt accurate, but as guns were usually held at the trunnions, and thus admitted of an extension of the material between the trunnions and the breech, it was evident that if such extension occurred, motion to a part of the mass would be set up, and the resulting pressure on the trunnions would be greater than the total powder-pressure at the bottom of the bore, as had been conceded by Sir F. Bramwell. This extension of the mass of the gun had constituted one of the main elements of Mr. Butter's argument, and it was difficult to see how it could be denied; and if it were accepted, it would not only at once meet the objection of Mr. Bashforth, but would also explain the results of the experiments of Colonel Sebert, brought forward by Mr. Canet, from which it was sought to be maintained that the gun and shot commenced their motion simultaneously; whereas the experiment only proved that the breech end of the gun and the shot did so, and this was precisely in accordance with his own statements. The delicate, and in most respects conclusive experiments on recoil, carried out by Colonel Sebert in France, were unknown to him previous to writing the Paper; but nevertheless he thought there was less in them to have led to any considerable modification of his views, had he known of them, than Mr. Canet assumed; on the contrary, they confirmed in a remarkable degree all the really important points he had advanced. For example, with respect to the universal use in this country of the formula of the equality of

Digitized by Google

momenta for finding the velocity of recoil, he had shown the necessity of the introduction into it of a constant, depending upon the kind of powder employed, and Mr. Canet, with all Colonel Sebert's results before him, had done the same; and it would appear from the Table and data given by Mr. Canet that Mr. Butter's formula would almost exactly meet the case. Again, he had from his observations drawn the conclusion that the recoil of the gun gradually attained its maximum after several inches of motion, and Colonel Sebert's experiments exactly confirmed this view, most important with regard to his calculations relative to the elastic field carriage; and further, he had asserted that recoil of the gun, as a whole, was not developed until the shot was near the muzzle, and this was so far confirmed, practically, by the experiments of Colonel Sebert, who proved that while the time of travel of the shot along the bore was 0·012 second, the time occupied in fully developing recoil was 0·041 second, or nearly four times as great; and whereas when the shot left the bore, the gun had only recoiled 1·2 inch, it did not attain its maximum velocity until it had passed over 7·9 inches. It appeared, therefore, that while they might differ as to the causes of the facts, which was after all of little importance, they agreed remarkably closely as to the facts themselves, so closely, indeed, that it was a matter of sincere pleasure to him to observe his main propositions so fully corroborated. He could not but express his surprise that Mr. Canet should have failed to have noticed this accordance between their results, unless on the supposition that his hostility to the theoretical views of the Paper rendered him indifferent to all other portions of it. With regard to his attack upon the theory, his definition of "inertia" was a singular one, but was sufficiently answered in Mr. Butter's reply to Mr. Bousfield. With respect to his statement that the velocity of recoil was 0 when the resistance was infinite, of course this must be so, but it was difficult to conceive how an infinite resistance could be practically set up. This was sought to be accomplished recently in the case of a 4-ton gun, which, in spite of a solid backing of iron and stone, embedded against a large bank of earth, recoiled 2 inches at the trunnions; this recoil could not have been detected but by careful automatic registry, as the gun immediately regained its normal position, the recoil being solely due to the compression and subsequent restitution by means of its elasticity, of the mass of the backing. With regard to the independent invention, by Mr. Vavasseur, of a field carriage for the French army of a similar kind to his, it was to be accounted for only on the ground that both took such interest in developing

Mr. Butter.

Digitized by Google

Mr. Butter. to the utmost the use of the hydraulic buffer, that when a reduction in the weight of field carriages became desirable, it was natural that each one should turn to this appliance as affording the best chance of enabling such reduction to be made. Once on this line of thought, it was inevitable that some degree of similarity should be developed in the designs; he was quite content to know that his design was original, and to concede the same to Mr. Vavasseur. A few observations had been made by Professor Fleeming Jenkin which he felt bound to notice. What he had already said concerning the causes of a disturbance of true equality of momenta, in answer to Professor Unwin, would constitute a sufficient answer to Professor Jenkin on this subject, whose statement that he was not acquainted with kinetics because he had used certain terms which to the modern, exacting system, seemed inexact, was, to say the least, a little uncharitable. It was presumed the definition of force, as that which produced or tended to produce motion, was still a canon of faith, and that in statics the word force was still admitted; if this were so, then there was force associated with motion, and force which was only pressure, because it was in equilibrium with some other force; and although the abstract idea of force rendered it possible to conceive of only one kind, yet in practice nothing was more common than to speak of force, when acting as a pressure, as "statical force," and when associated with motion as "dynamical force." At any rate, when he found that the late Dr. Whewell, Hon. M. Inst. C.E., used the expression, "statical forces are called pressures," he presumed that Whewell would be considered equally unacquainted with kineties, and he was quite content to be condemned in such company. Mr. White had evidently not viewed this matter in the same light as Professor Jenkin. The latter gentleman also stated he could not see how the "summation of all the powder-pressures was meant to be effected." If he would endeavour to realise the conditions which Mr. Butter considered to be associated with the peculiar problem of the discharge of a gun, he would see that the powder-pressures, acting only in the first stage upon the elasticity of the mass of the gun, became stored up in the general compression of the material, and afterwards, by restitution, acting against whatever resistances there might be, developed that force of recoil which he had incurred the Professor's disapprobation by terming dynamic. He was more justified in dissenting from the idea of the gun under any circumstances of discharge developing an energy approaching that of the shot, because this was not a different shade of meaning given to mere words, as were the other objections, but one of principle.

Digitized by Google

This, however, was, from Mr. Butter's point of view, possible; for, if time were allowed for the powder-pressure to complete its action upon the shot, the latter would have attained to such an enormous velocity in the same direction as that of the expansion of the gas, that when the pressure of the latter had practically ceased, so far as the shot was concerned, it would be very considerable upon the gun, which was moving at a comparatively slow rate. Now it was possible, looking to the peculiar character of the products of combustion and the nature of their action, that the far greater velocity of the shot during the later stages of movement in the bores of ordinary guns, at which time the shot was moving rapidly in the same direction as the waves of pressure, might result in a greater actual pressure upon the gun than the shot, and this was so far borne out by observation that it was a well-known fact that the crusher-gauges in the gun always registered a higher pressure than did those in the base of the shot; there would appear, therefore, to be grounds for believing that the reactions by which, in ordinary impact and pressures of a similar kind, the action was maintained uniform throughout at each instant, might admit, from the causes stated, of giving to the gun a higher degree of momentum, by prolonging the action, than to the shot. The fact was, the nature and action of discharge, so far as the gun was concerned, were so complex, and demanded so many careful observations before anything of a reliable nature could be determined, that a strict mathematical deduction regarding this question was at present impossible, as Mr. Bashforth had stated. In the meantime mathematicians need not be so sensitively jealous of their various laws and expressions; it was merely a question of their correct application. They had regarded the discharge of a gun as a simple question of impact, whereas it was a far more complicated action.

Mr. Butter.

A valuable investigation had been contributed by Dr. Pole, but this was founded upon the assumed mathematical conditions, which might, or might not, be near the actual truth; and the simple formula for the velocity of recoil, at which he had ultimately arrived, differed but little from Mr. Butter's formula; in both formulæ an assumed constant was introduced into the expression for the equality of momenta, and it would be interesting to apply both to the case of the 43-ton gun, in order to compare their results. The values of the symbols were as followed:—

W (weight of gun and carriage) .	114,240 lbs.
v (velocity of projectile) . . .	1,850 feet per second.
w (weight of shot)	710 lbs.
c (weight of charge)	285 „

Digitized by Google

Mr. Butter. Taking first Dr. Pole's formula:—

$$V = v \times \frac{w + \frac{3}{2} c}{W}$$

$$= 1{,}850 \times \frac{710 + \frac{3}{2}(285)}{114{,}240} = 18{\cdot}4 \text{ feet per second.}$$

Turning now to his formula—

$$V = v \times \frac{w + c}{W} \times \sqrt{\tfrac{4}{3}}$$

$$= 1{,}850 \times \frac{710 + 285}{114{,}240} \times \sqrt{\tfrac{4}{3}} = 18{\cdot}7 \text{ feet per second.}$$

And now referring to the Paper (p. 20), it would be seen that the velocities had been arrived at by three different methods, namely:—

From the formula	18·7
„ „ time waves of the curves	18·6
„ „ actual observed work of recoil	19·0
Mean	18·8 nearly.

It would thus be seen that while the two formulæ gave very similar results, the one by Dr. Pole, as in the case of the 10-inch gun, appeared to indicate a velocity somewhat lower than was the actual fact.

Quite recently he had availed himself of an opportunity of making some experiments on the resistance of inertia and its effect upon elastic bodies, which he thought were of importance in this discussion, and he would therefore describe them.

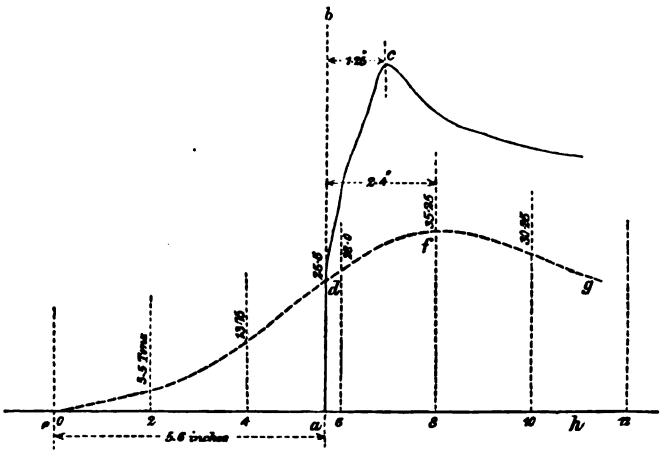
He had constructed a frame in which a polished plate was made to move accurately in a vertical direction. This frame was fixed to the body of the proof carriage, Fig. 3, Plate 2; a stud fastened to the gun block, moved, as the gun recoiled, along a diagonal groove at the back of the plate, thus causing it to descend in a perfectly vertical line; a heavy frame on the ground, carried at its upper end a steel point which was kept by a spring in contact with the surface of the polished plate. Supposing that the body of the carriage remained at rest while the gun recoiled, the plate would descend and the steel point would make a vertical line; but when motion commenced in the carriage a curved line would be drawn. A number of experiments had been carried out with this apparatus, and gave, under the same conditions, uniform results; by applying

Digitized by Google

it to different guns and thus varying the relations of the weights and velocities, some valuable data were obtained, but for the present purpose it would be sufficient to mention one instance as an example. The gun in this case was a 6-inch B. L. gun of 4 tons weight, firing a shot weighing 100 lbs. with a charge of 48 lbs. of powder; the highest velocity of the shot was 1,982 feet per second; the weight of the gun and its blocks was 92 cwt., and that of the carriage 176 cwt.; the former on recoil pressed the latter into motion with the force set up by the hydraulic buffers, and this force was measured by a pressure gauge at each round. The result was shewn in Fig. 6, which was one-half the size of the

Mr. Butter.

FIG. 6.



actual records. By this it was evident that the carriage remained at rest while the plate fell a distance of $a\,d$, and to admit of this amount of fall, the gun moved horizontally through the space $e\,a$ = 5·6 inches; at the point d the carriage began to move, and the steel point then became deflected from the straight line. When it reached c, the pressure caused by the resistance of the hydraulic buffer became so great that the whole carriage tilted upwards, causing the plate to describe the reverse curve as shown. The pressures acting upon the lower carriage to set it in motion were as stated on the various ordinates, and it would be seen that the pressure increased to 25·5 tons during the passage of the gun over the 5·6 inches, before the least motion was imparted to the carriage. This result he thought would assist greatly in making somewhat plainer the views he had advanced, and when carefully

Digitized by Google

Mr. Butter. considered must lead to some modification of the ideas on "inertia" which had been so freely advanced by Messrs. Bousfield, Canet, and other gentlemen, especially as the rails upon which the carriage rested had a decline of several degrees, which must have facilitated its starting into motion.

---

29 November, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

The discussion upon the Paper on "Forces and Strains of Recoil considered with Reference to the Elastic Field Gun-Carriage," by Mr. H. J. Butter, occupied the whole evening.

Digitized by Google

6 December, 1881.

JAMES ABERNETHY, F.R.S.E., President, in the Chair.

THE following Associate Members have been transferred by the Council to the class of

Members.

WILLIAM THOMAS HENNEY CARRINGTON.
ARCHIBALD CRELLIN CREGEEN.
GAVIN GEMMELL DICK.
DONALD MACDONALD FORD GASKIN.
JAMES GEORGE HENRY GLASS.
JOHN ALFRED JONES.
HENRY BATSON JOYNER.

The following Candidates have been admitted by the Council as

Students.

HAROLD ABBEY.
JAMES RANSON BAASS.
JOSEPH HENRY BAYNES.
THOMAS HUDSON BEARE.
HARRY ROBERTSON BEST.
CHARLES ZIETHEN BUNNING.
HARRY ARTHUR DIX.
HENRY WILLIAM TURNER DIXON.
OSBORNE ANTHONY GEORGE EDWARDS.
REGINALD EATON ELLIS.
FREDERICK ARTHUR FIELD.
BENJAMIN KINGTON FINNIMORE.
WILLIAM ROBERT FITZMAURICE.
EDWARD COLIN FOOTE.
HENRY WILLIAM HARGRAVE.
FRANK RICHARD HARRISON.
RICHARD JAMES HARTLEY.
JOSEPH HENRY HOWARD.
CHARLES HERBERT HUTTON.
WILLIAM STANDISH HALY HUTTON.
ARTHUR JOSEPH JACK.
WILLIAM ARTHUR JOHNS.
THOMAS KING.
ALEXANDER ANDERSON KYD.
JOHN KYLE, Jun.
EDOUARD ELIE LEFÉBURE.
JOHN RANDALL MANN.
WILLIAM MARTIN.
JAMES EDWARD MITCHELL.
WILLIAM OSMOND.
CHARLES STUART RUSSELL PALMER.
HENRY HOLLINWORTH PARKINSON.
ARTHUR ROBERT PENNY.
HERBERT WILMSHURST PEWTRESS.
JEFFERY MACKLIN PHILPOT.
THOMAS RAVENHILL.
JOHN CHARLES DODGSON RAPER.
JOHN SIMPSON ROPER.
JOHN ROSS.
ARTHUR BRUNEL RUMBALL.
WILLIAM CONNOR STEEL RUMBLE.
NORMAN SCORGIE.
RICHARD SMITH, Jun.
ROBERT CHARLES TAYLOR.
FRANCIS SALES THOMAS.
THOMAS THOMSON.
ALFRED TOBODE.
ARTHUR LAURENCE RIDLEY VERDON.
JAMES KYNASTON EDWARDS VERSCHOYLE.
WILLIAM HEAD MIDDLEMORE WALSH.
HERBERT FRANCIS WARING.
MAURICE WILSON.

Digitized by Google

The following Candidates were balloted for and duly elected as

Honorary Members.

Frederick Augustus Abel, C.B., F.R.S.
His Grace the Duke of Devonshire, K.G., F.R.S.
The Right Hon. Earl Granville, K.G., F.R.S.

Members.

Robert Nelson Boyd.
John Walker Buyers, M.A.
Edward Alexander Cameron.
George Cunningham, F.R.S.E.
Edward Rice Sweet-Escott.
William Evans.
Arthur Greenwood.
Henry Hack.
Arthur John Hughes.
Charles Booth Jones, B.A.
George Nugent Reynolds Lambert.
Thomas Bell Lightfoot.
Francis Joseph Lynch.
John Leonard McAlpine.
Andrew Noble, C.B., F.R.S.
John Russell.
William Edwin Thursfield.
John Franklyn Tyler.
James William Wells.

Associate Members.

Clement Henry Allen, Stud. Inst. C.E.
Henry Alty.
Thomas Andrews.
Ralph Archbould.
Samuel George Artingstall.
Charles John Seymour Baker, Stud. Inst. C.E.
John Beckett Baker.
Augustus Zachary Constant Belin.
Arthur Wilbraham Dillon Bell, Stud. Inst. C.E.
George Bell.
Christian Bentsen.
George Rowland Bird.
James William Blackett.
John Henry Briggs.
James Bull.
James Samuel Butler, Stud. Inst. C.E.
Henry William Butt.
Henry Benjamin Chapman.
Frank Chauntler, Stud. Inst. C.E.
Edward John Henry Christie.
Harry Bathurst Christie.
Archibald Ross Colquhoun.
Leslie Montgomery Connor, B.A.
Charles Friend Cooper, Stud. Inst. C.E.
Henry Croft, Stud. Inst. C.E.
George Parnall Culverwell, B.A.
Robert Davison, Jun.
James Diggle.
Ernest Gordon Fraser, Stud. Inst. C.E.
James Edward Fulton.
Henry Chudleigh Granville.
William Stukeley Gresley.
Beverley Griffin.
Gustav Hallé.
Harold Hayes Harker.
Robert William Lyons Hawkins.
Cecil Quixano Henriques, Stud. Inst. C.E.
Robert Nathaniel Hodges.
John Poictevin Hogan.
James Bernard Hunter, Stud. Inst. C.E.
Charles James.
Edward Homer Jeffreys, Stud. Inst. C.E.
John Alexander McDonald, Stud. Inst. C.E.
Frederic William Marchant.
William Michell.
William Millhouse.
Charles Algernon Moreing, Stud. Inst. C.E.
John Henry Nuttall.
Robert Stewart Oliver.
Hans Blom Olsen.
Thomas Ormiston Paterson.

Digitized by Google

Associate Members—continued.

HENRY DAVID ALEXANDER REID.
ERNEST JAMES RUMSBY.
HERBERT BLOMFIELD SMITH, Stud. Inst. C.E.
HUBERT LE GAY SOLLY, Stud. Inst. C.E.
FRANCIS JOSEPH EDWARD SPRING.
JAMES JOHN TALMAN.
FREDERICK HERBERT TULLOCH, Stud. Inst. C.E.
JAMES WALLACE, Stud. Inst. C.E.
RICHARD JOHN WOODS, B.E., Stud. Inst. C.E.

Associates.

THOMAS BRIDGES HEATHORN, *late Capt.* R.A.
THOMAS MCILWRAITH, LL.D.
JOHN FREDERIC MAIN, M.A., D.Sc.

(*Paper No. 1829.*)

"The Conservancy of Rivers: the Eastern Midland District of England." [1]

By WILLIAM HENRY WHEELER, M. Inst. C.E.

THE conservancy of the rivers of this country is a question continually growing in importance. It is one which must before long be dealt with by Parliament, and legislation effected which will necessitate considerable engineering works for putting the arterial drainage of the country on a more satisfactory footing. The frequent recurrence of floods, and the immense damage caused by them, cannot be allowed to go on without a remedy being sought.

Much valuable information as to the best method of forming a proper organization for the management of rivers has been elicited by Parliamentary Committees and public discussions on the subject, and individual engineering opinions have been given as to the way in which Floods Prevention Works should be carried out. No opportunity, however, has yet been afforded for a general expression of engineering opinion and discussion of the principles on which the regulation of rivers should be conducted. Such a discussion will be highly valuable, not only to those members of the Institution who may hereafter be called upon to carry out these works, but also as a basis for the guidance of those on whom lies the responsibility of deciding the best course to pursue, and of levying the money to pay for the works. From want of a clear perception of the principles which ought to guide all works for the improvement of rivers, great mistakes have been made, enormous sums of

[1] The discussion upon this Paper was taken together with that upon the succeeding one.

Digitized by Google

money have been wasted, and taxes levied from which little or no benefit has been derived.

The circumstances of river basins in this country are so various in character, owing to geological and economical causes, that it is not possible to lay down any method of dealing with all rivers alike. Still there are certain general principles that should prevail, and which should be borne steadily in mind in designing improvements, whether of a local or a general character. In the following Paper an endeavour will be made to show what in the Author's opinion these principles are, and to illustrate them by facts relating to one particular class of rivers.

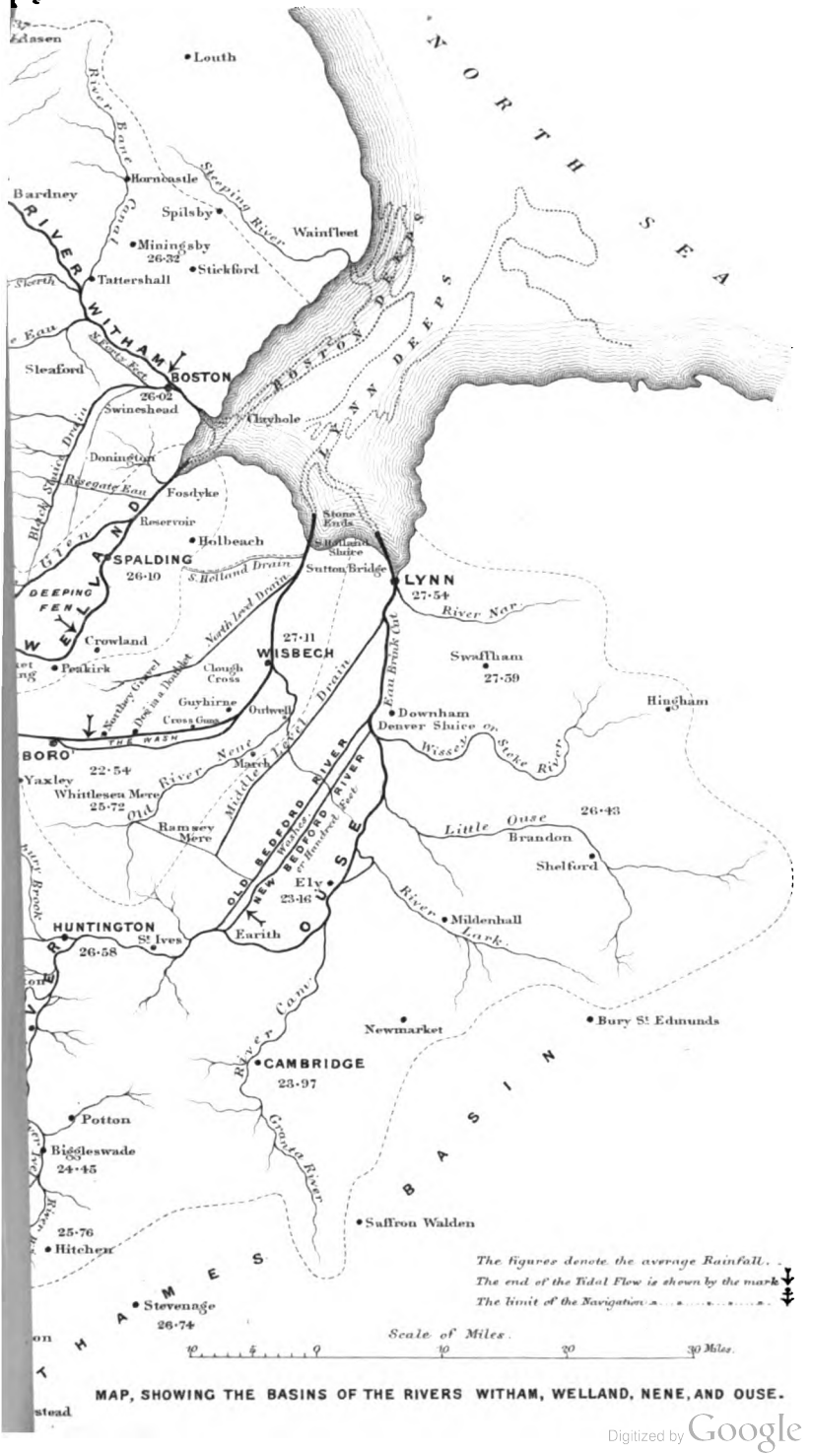
The rivers here dealt with are those draining the Eastern Midland portion of England, and are typical of the drainage systems of flat districts of permeable strata discharging into sandy estuaries, with a small rainfall, free from mountain torrents and rapid discharges of water met with in the watersheds of volcanic districts. The industry pursued on their banks being mainly of an agricultural character, no complication arises from the pollution by manufactories.

Large sums of money have been expended on these rivers, for which some of the lands draining by them are heavily taxed. Yet owing to the piecemeal way in which this has been done, these river basins are still subject to most disastrous floods. If the same amount of money had been judiciously expended on a comprehensive plan embracing the whole river system, and the cost fairly spread over the lands benefited, these rivers would now be in a comparatively efficient state, and competent to discharge the heaviest floods without any undue burden being imposed on the land.

The Eastern Midlands lying between the Trent, the Severn and the Thames (Plate 6), are drained by four rivers, the Witham, the Welland, the Nene, and the Ouse, which discharge into the upper end of a large indent or bay on the east coast known as "The Wash." There are other small rivers draining the district lying between the watersheds of the Ouse and the Thames, which discharge at various points along the coast, but these it is not intended to deal with. The area drained by the four rivers is about 5,719 square miles; their total length about 416 miles, and with the tributaries 872 miles. The number of square miles to a mile in length of the main stream is 12·74, or 8,155 acres for the whole watershed. Including the affluents there are about 4,015 acres to a mile of river.

These rivers drain portions of the counties of Lincoln, Norfolk,

Digitized by Google



MAP, SHOWING THE BASINS OF THE RIVERS WITHAM, WELLAND, NENE, AND OUSE.

Digitized by Google

Digitized by Google

Northampton, Cambridge, Huntingdon, Rutland, Bedford, and Buckingham. The principal towns within the watershed are Lincoln, Boston, Grantham, Spalding, Wisbech, Peterborough, Northampton, Lynn, Cambridge, Ely, Bedford, and Dunstable. With the exception of Northampton, where shoemaking is carried on to a large extent, and Bedford and Dunstable, where the straw-plaiting industry is chiefly located, these towns are mostly agricultural centres, and are markets for the disposal of the produce grown on the lands around. The businesses carried on are almost entirely those for the supply of agricultural machinery, for the manufacture of the produce for market, or of oil cake or other food for the stock, and of artificial manures for the land. The rainfall of the district is small, ranging from 17·39 inches in the driest seasons to 34·48 inches in the wettest; the average being 26·05 inches (Appendix I.).

The country generally is flat, and the elevation at the source of the rivers is only about 300 feet above the level of the sea. The geological formation is Kimmeridge and Oxford clays, Oolites with small deposits of Lower Greensand, Chalk and Glacial drift. The lower or fen districts are alluvium and peat. The sources of the four rivers are not more than about 30 miles apart, the water producing the streams breaking out from the Oolites near the extreme north-eastern boundary of the watershed of the Severn. The lower part of the watershed, comprising about 668,241 acres, is a plain, known as "The Fens," now a tract of valuable agricultural land, but formerly a morass, which in winter, with the exception of a few elevated spots, was little better than a lake, but in summer afforded valuable pasturage for the cattle of the occupiers of the adjoining high land. After the introduction of monastic life into this country, settlements took place in the Fens by some of the religious orders. The abbots and priors began gradually to improve portions of the fen, but no systematic attempt at reclamation was made until the seventeenth century, when certain speculators or "adventurers" undertook to drain and improve the fens in return for a share of the lands. The most successful of these was the Duke of Bedford, who reclaimed a large tract of land in Cambridge and Norfolk, known as "The Bedford Level," much of which is owned by the successors of the original "adventurer."

The adventurers called to their assistance Vermuyden, a Dutch engineer, who designed his works of reclamation on a plan similar to plans adopted in Holland. Losing sight of the greater range of the tides in the estuary than on the coast of his own

Digitized by Google

country, he took no advantage of the gain to be obtained by discharging the drainage direct into the estuary, where low water ebbs out lower than the North sea, and thus securing a natural outfall for the water. The outfalls were neglected, embankments were made along the main rivers, and long arterial cuts through the lands to be reclaimed, with sluices at the end to keep out the tidal waters. Under this system the lower part of these river-basins became split up into a number of districts or levels, each level dealing with its own drainage irrespective of its neighbours. The aggregate amount of money thus spent in the reclamation works was far greater than it would have been had all contributed to the improvement of the common outfall. Conflicting interests were created which have since caused enormous sums to be spent in litigation, and have prevented that common action for the improvement of the rivers which is generally admitted to be necessary, and adding greatly to the difficulties of the application of any system of river conservancy.

As the original works failed to attain the purpose for which they were intended, fresh cuts were made. In many instances the course of some rivers was entirely diverted. Long straight cuts were made to supersede the winding course of some natural rivers, shortening considerably the distance the water had to travel, and accelerating their discharge. In these new rivers the flood-banks were set in some cases as much as a mile apart, the river channel occupying a space in the centre sufficient only for the ordinary discharge of water. In floods the water overflowed the ordinary banks, and spread over these "Wash lands." The country below being at that time almost entirely open marsh, the outfalls were thus capable of receiving the flood-water, and the washes being unobstructed, the floods passed rapidly away without doing any damage to the land, which was then all under grass.

The marsh lands below these washes have subsequently been reclaimed, and the outfalls otherwise choked and impeded, and the washes have long ceased to answer the purpose for which they were originally intended. Where they have not been encroached upon by being embanked from the rivers, they now in times of flood become vast lakes, which fill with water on the overflowing of the rivers, sometimes to a depth of 6 feet, the water remaining on them for several weeks together, presenting the appearance of an inland sea. The proprietors having become possessors of portions of these washes at high prices, have sought to recoup themselves by endeavouring to grow crops of hay, and in many instances by turning the fields into arable land. During

Digitized by Google

the last few years, owing to the continuous floods, crops have been washed away, and the land rendered of little value. The miasma arising from this land, when at length it begins to dry, after several weeks' submergence, is prejudicial to health. Thus what were intended by the engineers who designed these wash lands as flood regulators, have, by the want of a general system of control, become a nuisance.

The existence of these washes, the large area they cover, and the above facts, are sufficient answers to those theorists who are in the habit of advocating the formation of reservoirs to regulate the streams and prevent floods. Here, on rivers draining comparatively a flat country, are occasional reservoirs of 3,000 and 5,000 acres, which yet have scarcely any effect in preventing most severe floods on the lands above them. Taking an average depth of water of 4 feet over the whole of the wash lands, those on the Nene would only provide for a rainfall of 0·297 inch over the watershed draining above them, and those on the Welland of 0·48 inch.

The Witham.

The Witham rises near Thistleton and South Witham, a few miles north of Stamford, at an elevation of 339 feet above the sea. It is about 89 miles in length, has five tributaries, the Brant, the Till, the Langworth, the Bane, and the Sleaford river, their united length being about 98 miles. The area of the basin drained is 1,063 square miles, of which 196,686 acres are fen lands. The number of acres to 1 mile in length of the river and its tributaries is 3,635. The tidal flow only extends 8 miles, the tide being arrested at Boston by a sluice placed across the river, having self-acting doors, which close against the tide and open on its receding. The tide flows from two to three hours, and at spring tides there is a navigable depth at the present time of about 16 feet. Mean high water on an average of four years (1869-72) rose 18·92 feet above the Black Sluice sill at Boston, or 10·22 feet above ordnance datum; spring tides, 22·02 feet; neaps, 15·36 feet. A spring tide which rose 23 feet 4 inches in Clayhole, rose 13 feet 2 inches at Boston; and a neap tide, which ranged 9 feet 2 inches in Clayhole, ranged 6 feet at Boston. By the works now being carried on under the Witham Outfall Act of 1880, it is expected to give a navigable depth of 22 feet at the proposed entrance to the new docks at Boston.

Between Boston and the lock at Bardney, a distance of 20 miles, water is maintained for purposes of navigation at a uniform

Digitized by Google

depth of 9 feet. The Commissioners have now, under the Act of 1881, obtained power to reduce this when necessary. In floods the regulating doors at the Grand Sluice at Boston are withdrawn, and the water allowed to flow without interruption. The sluice has four openings of 16 feet each, and the depth of water on the sill at ordinary floods is about 10 feet, rising as high as 14 feet in extreme floods. The fall in the surface of the water in floods between Bardney and Boston is from 3 to 5 inches per mile, and between Boston and the sea 25 inches per mile. The waterway of the river about 2 miles below Boston is 200 feet at low water. With 10 feet of water the area is 2,000 square feet. The area drained through this part of the channel is 650,392 acres, thus giving 325 acres to every square foot of waterway. The waterway of the Grand Sluice is 66 feet, and with a depth of 10 feet on the sill it has an area of 660 feet. The river above was originally excavated so as to give a mean waterway corresponding with that of the sluice. The number of acres draining through the sluice is about 448,835, being 680 acres to a square foot. The area of the river at Boston at ordinary low water is 156 square feet, and at high water of spring tides 2,286 square feet, a proportion of 1 to 14·6. But in comparing this with the other rivers, it must be borne in mind that the section is taken only 7 miles from the estuary, the tidal flow being arrested at the Grand Sluice, 1 mile further up the river.

The river has been considerably altered below the City of Lincoln, from which place it is mostly artificial. About the middle of the last century the banks on both sides of the river from Boston to Lincoln were raised and strengthened, the greatest of the bends removed by new straight cuts, and the channel generally deepened, widened, and improved. The Grand Sluice was erected for preventing the tide flowing into the upper reach of the river. These works were completed in 1766, at a cost of about £53,650. In 1811 a further amount of £30,000 was spent on this portion of the river. Additional works have been carried out under an Act obtained in 1865, for deepening and removing obstructions from the channel, and strengthening and raising the banks. The cost was about £50,000. The navigation authorities have expended, during the last fifty years, about £60,000 in straightening and training the tidal portion of the river below Boston. Under an Act obtained in 1880, works are now being carried out for making a new outfall by a cut 2½ miles in length, by which the distance will be shortened 1½ mile, and the shifting sands at the mouth of the river avoided. It is expected that this

Digitized by Google

will give a relief of at least 3 feet in the low-water mark at the drainage sluices.

The cost of the works executed up to the present time is upwards of £300,000, and the works for the outfall are estimated to cost £120,000 more. Beyond this a large sum has been spent on works for improving the river by the owners of the upper navigation. The cost has been met by taxes on the low lands and by dues on the shipping. The taxes on the fen lands for river works vary from 1*s.* to 5*s.* 6*d.* an acre, in addition to what has to be paid for works of interior improvement, which on some of the fens brings the amount of drainage taxation up to 16*s.* per acre. This amount extends over a length of 35 miles of the lower part of the river, or only about one half of its course. Further expense has been incurred in straightening and improving the upper reaches, by which the water is discharged more rapidly into the lower part, but the landowners contribute nothing to the works below Lincoln. Notwithstanding the improvements, the river is incapable of discharging the water as quickly as it is poured into it, owing to the defective outfall at the sea, to the obstruction caused by the sluice at Boston, the weirs at Lincoln, and the inadequacy of the channel between those places, and consequently the floods on this river have been increasingly frequent and disastrous. The lower part of the city of Lincoln has been several times under water, the houses for a time being rendered uninhabitable and the large engineering works stopped. In the winter of 1876, when several of the interior banks were broken, 40,000 acres of land were under water, people were driven from their houses, and cropping was lost to the estimated value of £100,000. In 1878 and 1879 there were very heavy floods; and in the autumn of 1880 a large tract of land was again submerged; the corn stacks were standing several feet in water, and sheaves of corn which had not been carried away were floating about in the fields. Not only were the farmers injured, but much valuable food was destroyed.

The Welland.

The Welland rises in a gentle range of hills between Lutterworth and Market Harborough, near the source of the Ise, a tributary of the Nene. It is about 72 miles long, has three tributaries, together 65 miles long, and drains about 707 square miles, of which 76,854 acres are fen land. The number of acres to 1 mile in length of the river and its principal tributaries is 3,302.

The Welland has a tidal course of 20 miles; extreme tides reach

Digitized by Google

as far as Crowland. A spring tide which rose 23 feet 4 inches at Clayhole rose 12 feet 2 inches at Fosdyke bridge, 8 miles from the estuary, and 4 feet at Spalding, 15 miles from the estuary. When the river is thoroughly scoured out to its full depth the rise at spring tides is 8 feet, giving 10 feet at high water of spring tides. The range of a neap tide, which was 9 feet 2 inches at Clayhole, was 5 feet 5 inches at Fosdyke, but the tide did not reach Spalding.

The mean inclination of the surface of the water between Spalding and Clayhole at ordinary low water is 14 inches per mile. During floods, in the trained portion of the channel below Fosdyke bridge, the inclination is 9 inches per mile, and between Fosdyke and Spalding 2 feet per mile. In large floods the average inclination from Spalding to low water of spring tides in the estuary, 15 miles, is 21 inches per mile. Owing to the want of prolongation of the trained channel, the fall from Fosdyke bridge to low water in Clayhole, 8 miles, averages about 18 inches per mile, due to the great fall between the end of the trained work and Clayhole.

The average waterway of the river at Spalding is about 40 feet, and the area in floods 400 square feet. The drainage area discharging there 300,000 acres, giving 750 acres to a square foot. The mean width of the trained channel below Fosdyke is 120 feet; the area of the waterway with 10 feet depth of water is 1,200 square feet. The drainage area discharging through this channel is about 452,480 acres, or 377 acres to a square foot.

The area at Spalding at low water is about 73 square feet, and at high water spring tides 485 square feet, a proportion of 6·65 to 1.

The Welland retains its ancient course more nearly than any of the other rivers, yet it has been considerably altered. The river was made navigable from Stamford to the sea by improvements in the channel of the river, straightening the same by new cuts, and by the erection of locks, &c., the first lock on the river being about 13 miles above Spalding. Subsequently the adventurers of Deeping fen, in order to obtain a better outfall for their drainage, widened and deepened the river below Spalding. In the year 1801 a new cut was made from the reservoir 8 miles below Spalding, and the open marshes above Fosdyke were enclosed. About forty-five years ago the work of training the river by fascine work through the shifting sands below Fosdyke bridge was commenced and continued for a length of 3 miles 30 chains. This training had the effect of lowering the low-water level at Fosdyke bridge 7 feet. The whole of these works, so far as they relate to the improvement of the river as the outfall of the drainage of the country, were paid for by the Fen land in the

Digitized by Google

low level of the river basin, assisted by dues levied on the shipping using the artificial channels.

The arterial drainage of this district is still in a very defective condition, the channel not being sufficiently adapted to carry off the rainfall as rapidly as it is collected in the river. The banks which protect the fens are constantly being broken, owing to the channel being overfull and the fens flooded. The repeated floods of the last few years have done an immense amount of damage by submerging the land and destroying the crops. In July, 1880, in addition to thousands of acres of land which were submerged, the whole of the lower part of the town of Stamford was flooded, as were also the villages of Market Deeping, Elton, Maxey, and others on the course of the river, the water rising to a height of 3 and 4 feet in some of the houses. Again, in the autumn of the same year, a flood, almost as extensive and if anything more disastrous in its results, occurred. Although floods so calamitous are exceptional, yet their frequency and the large area of land thrown out of cultivation, are sufficient to demand that such alterations should be made in the river, as the main outfall of the drainage of the district, as to render it efficient for its purpose.

The Nene.

The Nene rises in two springs at Daventry, and owing to its windings, although in a direct course the distance is only 60 miles, the length of the river is 99 miles. It has three tributaries; the Ise, the Harper, and Willow Brook, their united length being 52 miles.

The Nene has a drainage area of about 1,055 square miles. The number of acres to 1 mile in length of the river and its tributaries is 4,474.

The tidal flow is 34 miles, at spring tides, reaching Northey Gravel within 2¾ miles of Peterborough, and at extreme tides even as far as Peterborough. The tide flows three and a half hours at Sutton bridge, 7 miles from the estuary, and two and three quarter hours at Wisbech, 15 miles from the estuary. A spring tide, which rose 23 feet 3 inches in the estuary, rose 20 feet 6 inches at Sutton bridge, and 15 feet 2 inches at Wisbech. A neap tide, of which the range was 9 feet 1 inch in the estuary, ranged 8 feet 5 inches at Wisbech. The navigable depth of water at Wisbech is about 22 feet at high water spring tides, and 3 feet at low water. From observations made by Sir John Coode, M. Inst. C.E., it appears that, owing to the tide being throttled by the contracted form of the lower part of the channel, it has not

Digitized by Google

free ingress and egress, and does not reach the limit of its flow until some time after the ebb has commenced at the lower end. Thus the particular tide observed ebbed three and a quarter hours at the lower end of the trained portion of the channel before it had reached the "Dog in a Doublet," 25 miles above, and then continued flowing there for forty-five minutes. The water rose 6 feet at the upper end, while it fell 6 feet 11 inches at the lower end. Thus there are two strong currents in the river running simultaneously in opposite directions, the ebb towards the sea and the flow towards Peterborough. High water spring tides is 7 feet lower at Peterborough than at the outfall at Stone Ends, and at neap tides it is 8 inches lower at Cross Guns, 24 miles from the outfall.

The mean inclination of the surface of the water at low water from Peterborough to the sea is at the rate of 5·63 inches per mile. This rate varies considerably along the different sections, the minimum being 2 inches per mile along the lower reach, and the maximum at the Horse Shoe bend at Wisbech 14½ inches per mile. In severe floods the inclination from the South Holland sluice above Sutton bridge to low water at spring tides in the estuary, 8¼ miles, is at the rate of 10½ inches per mile. Through Wisbech, in great floods, there is a fall of 3 feet in less than a mile.

The mean waterway of the river in the upper reach, a short distance above Wisbech, is 50 feet, giving an area with 10 feet depth of water of 500 square feet. The area of land draining through this part of the river is about 564,700 acres, or 1,129½ acres to a square foot. In the lower reach, between the stone banks of the trained channel, the waterway is about 220 feet, and with a depth of 10 feet the river has an area of 2,200 square feet. The area of land drained is about 675,200 acres, being 307 acres to a foot. Taking the area above Wisbech at ordinary low water at 240 square feet, and at high water of spring tides 1,595 square feet, the proportion of tidal to fresh water for the ordinary flow is 6·65 to 1.

The Nene is navigable from Northampton; it enters the fens at Peterborough, and then divides into two branches, one branch, the old river, joins the Ouse by a branch from Stanground sluice. The main stream runs by Smith's Leam through the wash lands and Wisbech to the sea. The Nene has been more altered by various works than any other river. From Peterborough to the sea it is nearly a new river. Bishop Morton in 1478–86 first commenced the alterations, diverting the river from its original course by a new cut from Peterborough to

Digitized by Google

the water 7 miles. In 1726 the present channel of the river between Peterborough and Guyhirne was made, its course being parallel with Morton's Leam. The banks are about ½ mile apart, leaving 3,500 acres of low-lying meadow land or "washes." At Guyhirne, 6 miles above Wisbech, these banks come together and are close upon the river. From the Horse Shoe bend towards the sea below Wisbech a channel was cut by King Charles. In 1773 a new cut was made 1½ mile in length 5 miles from Wisbech, since known as "Kinderley cut;" and between 1827 and 1832 this was continued by the Woodhouse, or "Pauper's cut," so called from a number of paupers having been employed on the works. About fifty years ago the improvement of the river below these cuts was continued by excavating and scouring a new channel through the Cross Key washes from Gunthorpe sluice to Crab's Hole, a distance of 5 miles, with further training banks through the sands about 1½ mile in length. A large tract of land was at the same time reclaimed. The new outfall lowered the low water at the North-Level sluice 10 feet. In 1813, before the last improvement was made, the fall in the surface of the river was at the rate of 3 feet per mile. Afterwards it was only 3 inches in the mile. In 1852 further powers were obtained for improving the river between Peterborough and the sea, and after an expenditure of £200,000 the works were discontinued without any material improvement having been effected. The alteration in the channel of the river greatly augmented the range of the tides. In 1769, according to a report of Golborne,[1] spring tides only rose 4 feet at Wisbech, and neap tides did not reach the town; after the new channel was made they rose from 15 to 16 feet.

Within the last century the amount spent on the improvement of the main channel of the Nene has been upwards of £450,000, about one-fourth of which sum was raised on the navigation dues, to meet which all ships entering the port are subject to a charge of 1*s.* 0½*d.* per ton-register, and the remainder by the fen land. The taxes on the land to meet this outlay reach in some cases 15*s.* an acre, and yet the land is occasionally flooded. The river is in a most unsatisfactory condition, thousands of acres of land along the valley being sometimes inundated, and even the streets of Peterborough flooded and people driven from their houses, while the whole arterial drainage system suffers from its defective condition.

[1] *Vide* The Report of John Golborne, Engineer, concerning the drainage of the North Level of the Fens, and the outfall of the Wisbeach River. [Inst. C.E. Tracts. 4to. Vol. liv.]

Digitized by Google

The Ouse.

The Ouse rises at an elevation of 300 feet above the sea in numerous springs; these escape from the Oolite escarpment at its junction with the Lias Clay above the valley of the Cherwell, between the Ouse and the Thames, and within 4 miles of one of the sources of the Nene. The head of the main branch is about 87 miles from the sea, but owing to the tortuous course of the river the length of the channel is 156 miles. It has ten tributaries, their united length being 241 miles. The drainage area is 2,894 square miles. The number of acres to 1 mile in length of river and tributaries is 4,672. The river for the last 50 miles of its course runs through a flat low-lying district, and has been embanked from St. Ives downwards. Spring tides flow a considerable distance up the Hundred-Foot river, or nearly to Earith, 20 miles beyond Denver sluice, giving a tidal course of 40 miles.

The average rise of a spring tide at the Free bridge above Lynn, as taken from the records observed there over a period of seven years (1869–75) was 18·51 feet above zero, which is about 1·31 foot above low water of spring tides. The highest tide observed during that period was 22 feet 6 inches, an average neap tide was 12·04 feet, and the mean of all tides 15·54 feet, or 10·59 feet above ordnance datum. A spring tide, which rose 23 feet 3 inches above low water in Lynn Roads, rose 22 feet 6 inches at Lynn; and a neap tide, which ranged 9 feet 1 inch in the estuary, ranged 9 feet 5 inches at Lynn. The tide flows for about five hours at Lynn.

The ordinary low-water inclination of the surface of the water along the Eau Brink cut is about 3 inches per mile. In large floods the mean inclination from Denver sluice to low water in the estuary, a distance of 19 miles, is at the rate of 9 inches per mile. From Denver to Lynn the surface inclination is 12 inches, and from Lynn to the estuary 8 inches.

The area of the waterway of the river above Earith is very irregular. That of the channel near Earith is only 243 square feet, while 7 miles further up, the river, near St. Ives, has a sectional area of 672 square feet. At Over Court Ferry the area is 492 square feet. The area of the outlets for flood-water above Earith was found by Mr. Abernethy, President Inst. C.E., in 1875 to be 4,233 square feet, while below the Seven-hole sluice at Earith it was only 2,058 square feet. The shuttles at the Seven-hole sluice are not lifted till the flood-waters have risen 4 feet 6 inches above the level of the wash lands, or until a large part of

Digitized by Google

Wisbech, about 11 miles in length, which shortened the course of the country, is flooded. The fall in floods from the upper to the lower side of this sluice is 2 feet, caused by its restricted size as an outlet for the large area which has to drain through the sluice. In the Eau Brink cut the area in floods is about 2,620 square feet; and the drainage area being 1,852,160 acres, gives about 707 acres to a foot. In the Marsh cut the dimensions of the cut, originally set out with slopes 4 to 1, have increased by the washing away of the banks from 265 feet at the bottom to an average of 425 feet, and from 500 feet at the top to an average of 594 feet. The depth originally was 10 feet 4 inches, and now varies from 10 feet to 19 feet, averaging 12 feet 8 inches. The channel below the Marsh cut, where it is confined by guide-walls of stones and fascines, is 400 feet wide, and, taking the depth at 19 feet, gives 463 acres to a foot of sectional area of waterway.

The section of the Eau Brink cut has also become very irregular since its first formation. From a number of measurements in 1862 it was found that the sectional area at low water in some places was double that in others, and the depth at low water varied from 17 feet 3 inches to 2 feet 9 inches. The mean of forty-three measurements gave the area at ordinary low water as 1,824 square feet, and at high water of spring tides 9,421 square feet, a proportion of 5·16 to 1.

The average low-water level of ten years, 1844–53, previous to the completion of the Marsh Cut, was 2 feet 5½ inches above the datum at the Free bridge, and for ten years after the opening of the cut, 1866–75, 9¼ inches below, showing an average gain of 3 feet 2¾ inches. The extreme low water varies from 3 feet 6 inches above datum to 3 feet 6 inches below, or a range of 7 feet. The average low-water level of spring tides at the Free bridge is now about 1 foot 3¾ inches below datum, or 3 feet 8 inches above low-water spring tides in the estuary; and during neap tides 2¾ inches above datum, or 5 feet 3 inches above low water.

The Ouse stands first of all the Fen rivers in the large amount of money which has been expended in its improvement. Without taking account of what was done by the early adventurers, upwards of £800,000 have been raised and expended in making new cuts, and otherwise improving that portion of the river which passes through the Fen land. The benefit of these improvements has been enormous, the low-water level having been depressed 12 feet.

Digitized by Google

Vermuyden began the alterations in this river in 1638 by making a new cut 21 miles long and 70 feet wide, called the Old Bedford river, from Earith, where the river enters the fen jurisdiction, to Denver sluice. In 1652 the New Bedford, or Hundred-Foot river, was made parallel with the other; and banks were raised on the north side of the old Bedford river and the south side of the new river, leaving an area of 5,000 acres of wash lands between. By this cut the course of the river was shortened 10 miles; and the old course of the river being maintained, there were three channels for the river. In 1748 Denver sluice was erected, by which the tidal flow was stopped from going up the old river course, but was still allowed a free run up the Hundred-Foot river. Subsequently the Hermitage, or Seven-hole sluice, was erected at Earith, and all the water coming from the basin of the Ouse above this, extending to 756,000 acres, was discharged by the new river, while the old Bedford river and the wash lands afforded receptacles for the waters in extreme floods. By an Act passed in 1812 the owners were allowed partly to embank the washes, and they have since been gradually encroached upon, their use as flood-regulators being otherwise destroyed.

The Eau Brink cut was originally projected by Kinderley in 1720, and the Act was obtained in 1795; but it was not completed until 1821. The original estimate was £39,985; the ultimate cost, £600,000. The length of the cut is 2½ miles, the old course of the river being 5 miles. The effect of the cut was to lower the low water 6 feet at Denver sluice, and 8 to 9 feet at Eau Brink, where the new cut joined the old river. In 1853 the Norfolk Estuary Company made a new cut through the marshes below Lynn 2 miles in length, and continued the channel by training through the Vinegar middle sands for a distance of about a mile. The cost of this work was upwards of £200,000, towards which the drainage and the navigation contributed £110,000. This cut shortened the course of the river, and depressed the low-water level 3 feet at Lynn. Since the opening of the Marsh cut the river has been further improved by dredging away a large clay bar or shoal lying between the Eau Brink cut and the Marsh cut.

Inland Navigation.

The present condition of the inland navigation seriously affects these rivers, and is one chief cause of their incapacity for carrying away flood-waters. Owing to the position of the Wash with reference to the Netherlands and the Continent, Lynn and Boston

Digitized by Google

were once prominent ports, ranking only second to London and Bristol; and although a great portion of this trade was diverted by the opening up of Hull and other ports on the east coast, yet up to the time of the construction of railways there was a large export trade of wheat and agricultural products, and an import of coals and other goods which were distributed throughout the midland part of England by these rivers. Water carriage was almost the only means of conveying heavy products into the country, and of exporting the corn and wool; as this traffic increased, the rivers, where they became shallow, were canalised and made navigable by locks or staunches. Thus Bedford by the Ouse, Northampton by the Nene, Stamford by the Welland, and Lincoln by the Witham, with other smaller towns, were placed in communication with the sea.

So long as these navigations were maintained in order, the shoals cleaned out as they accumulated, the locks and staunches preserved in efficient condition, and the weeds cut or kept down by the traffic of the boats, the rivers even in their artificial state of canalisation were capable of discharging the flood-waters; but since railways have diverted the traffic from these inland rivers, navigation has ceased, the works have gone to ruin for want of funds to maintain them, and shoals and weeds choke the channels. The rivers have become in a far worse condition to discharge the drainage of the country than when left in their natural state, and constant floods are the consequence. The proprietors of the navigations, who have suffered greatly by the loss of the dues, although unable to fulfil the duties belonging to a proper maintenance of the streams, still cling to the remnant of traffic left. For this they adhere to their rights as to the holding up of the water, without having the means to adapt the rivers to the modern requirement of drainage by enlarging the capacity of the weirs, so as in times of flood to discharge waters sent down at a much greater rate than formerly.

On the Witham, for a distance of 30 miles between Boston and Lincoln, the river is practically a canal. The tide is stopped by a sluice at Boston, and a weir and locks had to be constructed at Bardney and Lincoln. The inland water is held up to a constant height on the sill of this sluice by penstocks, for the purposes of the navigation. The navigation having been taken over by the Great Northern Railway Company, the works are maintained in efficient condition, but the obligation imposed by the original Act of holding up the water seriously affects the drainage. The river Slea, from Sleaford to the Witham, was made into a canal in 1792.

Digitized by Google

The navigation on this river having almost entirely ceased, the company was dissolved by an Act recently obtained. The Bane, another affluent of the Witham, was also canalised, forming a navigation from the Witham to the town of Horncastle; but the dues obtained are insufficient to maintain the works in proper order.

On the Nene, which is canalised from Peterborough to Northampton, the navigation is reduced to a few barges. The constant floods on this river are ascribed in a great measure to the defective condition of the works. The proprietors of the navigation, on whom was cast the duty of maintaining the river, no longer have the funds, and there is nobody to take their place. The same thing has occurred on the Ouse between Earith and Bedford.

On some of the affluents of these rivers, which under legislative powers granted last century had been converted into "navigations," the proprietors have obtained Acts of Parliament relieving them of their rights and liabilities, and there is now no jurisdiction over these rivers, or anybody responsible for removing shoals or cutting weeds. The beds of these streams have consequently grown shallow, and the rivers are no longer capable of acting as efficient arterial drains. Thus on the Ivel, an affluent of the Ouse, the navigation trust created in the reign of George II., was abolished in 1876. The river is said to have since diminished one-half in width and one-half in depth, and the bottom is being gradually raised above the level of the land. In like manner the Lark, another canalised affluent, has almost entirely silted up since the navigation of the river ceased. The Ouse itself above Earith is obstructed by numerous shoals, and an enormous growth of weeds. These were originally kept down by the constant passage of the vessels, and the shoals were removed by the trustees of the navigation.

It is no doubt a great advantage to the water supply, and also for the water power of the country through which these rivers pass, and conducive to the economical conveyance of gravel, stone, lime, manures, and other heavy materials, where time is of no great consequence, that the locks, weirs, and works should not be abandoned, and the rivers restored to their natural state; but it is desirable that these works should be placed under a jurisdiction interested in and having control over the drainage, and that by the enlargement and improvement of the weirs and other works the rivers should be placed in a state of efficiency.

Digitized by Google

Cause of Floods.

From the improved system of drainage now pursued, necessitated by the higher cultivation of the land, the rain is more rapidly discharged into the rivers. The water is no longer suffered to fill the land like a sponge, and pass off either by evaporation or slow percolation through the subsoil, but rapidly soaks through the soil broken up and disintegrated by steam ploughing and deep cultivation, and as soon as the sub-stratum is saturated to the level of the drain-pipes, the rain-water is carried to the ditches. Efficient pipe drainage necessitates clean ditches, and the straightening and improving of all arterial drains and minor watercourses. Thus every impediment is removed from the free flow of the water to the river. Large tracts of water known as meres, which formerly acted as reservoirs, have been drained; woods and plantations which absorbed and held the rainfall have been stubbed up. Villages and towns are drained, and everywhere, whether in town or country, every effort is made to prevent stagnation, and speedily to void the water. An increase in the rainfall has also no doubt contributed to the increase of floods. On examining the statistics of rainfall kept at Boston for the past fifty years, it appears that there has been a considerable increase in the annual rainfall during the last few years, and especially during the last five. The average annual rainfall of the last five years has been 29·04 inches, or a greater quantity than previously recorded during a like period, and 5·62 inches above the average of the last fifty years. The next wettest period was 1846-50, when the average annual fall was 4·22 inches less than during the last five years. Taking ten-year periods, the average annual rainfall of the last ten years has been 4·34 inches greater than of the previous ten years, and 4·78 inches more than the ten years 1851-60, and 1·83 inch over 1841-50. Taking twenty-year periods, the last twenty years is 1·14 inch in excess of the previous twenty years and 4·11 inches in excess of the previous fourteen years. The largest increase has been in the months of September, February, and December, and the least in July and October. During the last few years September has had the greatest fall, and March the least (Appendix II.)

Meantime no provision has been made to meet this more rapid discharge. In the upper reaches of the rivers no adequate jurisdiction exists to prevent obstructions, to compel the maintenance of works, or to levy taxes for carrying out improvements. In the lower reaches the works have been done in sections, and without reference to the general drainage-system of the rivers,

Digitized by Google

and have been for the benefit of, and are paid by, the low lands, the owners of which of course are opposed to any improvements which will bring the upland waters on to them more rapidly. In fact, so jealous are the managers of the lower reaches of the river, that powers have been obtained enabling them to regulate the quantity arriving from the upper reaches. On the Ouse at Earith a sluice regulates the flow of water from above, in which the openings are not only too contracted to allow the flood-waters to pass freely through, but the shuttles are not lifted until the water has risen to more than flood-height on the lands above. In the Witham, at Lincoln, the quantity of the discharge is regulated by a weir, which is inadequate in times of flood, but any increase in the size of which is prevented by the Commissioners having the control of the drainage below, the consequence being that the lower part of the city and upwards of 15,000 acres of land above this weir are frequently flooded.

The openings of the bridges across the rivers, most of which were built before the conditions of drainage were altered, are many of them totally inadequate to the discharge of the waters, and great discrepancies exist in the area of the waterways. Thus Mr. Abernethy states in his report on the Ouse that the bridges over the Hundred-Foot river have only half the area of the waterway of those at St. Ives 12 or 13 miles higher up.

The growth of weeds, and the increase in the cesses or banks of the rivers which have gradually encroached on the waterway, form another serious and increasing obstruction. Owing to the careless way in which the weeds are cut in some of the rivers, they are allowed to float down the stream, settling in the shallow places where sand and alluvium collect, in time forming large shoals, and even islands, in the centre of the streams.

Where watermills exist there is no jurisdiction to compel the miller to maintain his works and regulate the weirs so as to give sufficient waterway in times of flood. Water-power is too valuable to be done away with, and the holding up of the water is a great advantage to the locality; but the owner should be placed under such restrictions that his weir and by-passes should be of sufficient capacity, and he should not be allowed to interfere with the efficient discharge of the water during floods.

In like manner the weirs belonging to the navigation need remodelling, and the works to be placed under an efficient system of supervision along the whole river.

The effect of the floods of recent years has been most disastrous to the owners and occupiers of land from the losses they have

Digitized by Google

incurred, and to the nation generally from the immense amount of produce destroyed. Thousands of acres of corn have been ruined by the summer floods, and land has been put out of cultivation by floods in the winter. The hay crops have been floated off the meadows and carried down the rivers, and a large area of rich pasture land has been so long inundated that the herbage has been rendered valueless. Additional taxes have also to be levied to pay for breaches in the river and drain banks caused by the floods, and for the maintenance of steam-power to pump the water off the flooded lands. It is not easy to calculate the loss which has been incurred during the last few years, but it certainly very far exceeds any sum required to place these rivers in a satisfactory condition.

Remedy.

The works necessary for the prevention of floods in these rivers require to be carried out on a comprehensive scheme, commencing with the outfall and working upwards throughout the whole length of the channel.

The four rivers here specially referred to, discharging into the head of a bay or estuary abounding in shifting sands, are liable to have their mouths choked. The conflict between the ebb current and the flood invariably has a tendency to throw up a bar at the point where the confined channel debouches into the open. All works of improvement in the way of training and confining the channels ought therefore to be progressive and continuous, gradually pushing the confined channel forward to deep water.

In carrying out these training works the walls require to be at such a height and width as to prevent any retardation or choking of the tidal flow. The object to be sought is to give a free action to the tidal current as the principal agent in maintaining these channels in their most efficient condition, and to ensure that the last of the ebb shall be directed along a definite channel, so as to take every advantage of its scouring power. For this purpose the width of the channel should decrease from the sea gradually, and the training walls, commencing at the lower end with a height equal to low water of neap tides, should, as they advance, reach to that of half-tide level.

Already the outfalls of the Nene and of the Ouse, which had been trained to deep water, are encumbered with sand. In the Nene the depth of water at the end of the trained channel has gradually decreased from 9 feet to 2 feet, the depth in the trained portion being 8 feet. Across the outfall of the Ouse there is a sand-bar,

Digitized by Google

with only a depth of water 5 feet against 9 feet in the trained channel. In both cases the training requires to be carried seaward slowly, but continuously, or the advantages gained will disappear. The Welland discharges into a sand bed 4 miles distant from deep water; in fact, it may be said that when the water leaves the fascine work it no longer has any defined channel, but meanders over the sands, continually shifting its course. The Witham is in the same condition, but works are now being executed to carry the channel to deep water.

Notwithstanding the bars forming at the mouths of the Nene and the Ouse, the advantage of the improvements already effected in the outfalls of those channels is shown by a comparison of the level of low water in floods with that of the Witham. Taking each river at a point 8 miles from the estuary, the average level of low water of the same flood over a period of seven days was 16 feet 6 inches above low water of spring tides in the estuary in the Witham; in the Nene 7 feet 7 inches above, and in the Ouse 5 feet 6 inches above; showing a difference of 11 feet in the low-water level between the Ouse and the Witham.

The Author has not been able to collect sufficient data to form any definite opinion as to the result of the works carried out in these rivers in raising or lowering the level of high water; but by a comparison of four years' tides at Lynn and Boston, it appears that mean high water is about 4 inches higher at Lynn than at Boston, which would show that the proper regulation of the channel has not a tendency to lower the high-water mark.

The value of tidal waters in maintaining the channels of these rivers in an efficient condition is of the utmost importance; and the deductions drawn from observations lead the Author to an opposite conclusion to that laid down in the Paper by Mr. W. R. Browne, M. Inst. C.E., on the relative value of tidal and upland waters in maintaining rivers, estuaries, and harbours.[1] It is not contended that the enclosure of the marshes reclaimed by the training works has had any material influence on the outfall, the silting up of which is, as already explained, due to other causes, and would equally have taken place had these marshes remained open; but for the maintenance of the channel a free flow and ebb of the tidal water up and down the river is essential to prevent the sand carried up with the tide from being deposited. So long as the water is in motion only a small portion of the sand which is held in suspension settles; but where there is an obstruction to

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxvi., p. 1.

Digitized by Google

the tidal flow, and the water remains quiet, the heavy particles at once begin to sink and accumulate. In summer, when the flow of fresh water is small, this deposit remains. The quantity of water at spring tides in the embanked channels of these rivers is ordinarily six times as great as the upland water, and, being always in motion, must therefore have a greater effect in maintaining the channels of the rivers. The Ouse is in the best condition to allow a free run of tidal water; the Witham the worst. In the former river the tidal flow is 40 miles, and, even in the driest season, scarcely any silting up of the reaches of the channel occurs. In the latter the tidal flow is only 7 miles, the tide being stopped by a sluice; the deposits have been so great in dry seasons as to raise the bed of the river upwards of 11 feet at the upper end, and an average of 8 feet over the whole length of the trained portion of the channel, leaving upwards of 1,500,000 tons of silt and sand to be washed out by the winter floods, which have had to rise nearly high enough to submerge the country before they could flow over the deposit. In the Welland, which has a smaller drainage area, but a tidal flow of 20 miles, during the same season the depth of the deposit left at the head of the tides did not amount to more than 2 feet 6 inches.

Following the improvement of the outfall, the channel requires regulating throughout its whole length by widening and deepening in parts and confining the low-water level where too wide so as to give a general uniformity throughout. Too great a width impedes the free discharge almost as much as where the channel is too restricted. By the diminution in the velocity of the current owing to the greater capacity, deposits take place and shoals are formed through which the water continually alters its course as the ebb or the flood current is the stronger. In the Marsh cut of the Ouse the banks have been gradually washed away, and the channel has become considerably wider than in the trained portion below; consequently shoals are forming, and the section of the channel has become very irregular, causing disturbance and increased friction and restricting the area of discharge.

Where the water is held up in the upper reaches, the weirs should be adapted to the largest flood discharge, as should all bridges and other structures across the waterway. While sufficient waterway should be secured for all floods, the low-water channel should be so restricted as to maintain its scouring power in the fullest efficiency. It is in the adaptation of the channel to the normal flow, and also to the flood discharge, that the greatest difficulty occurs. The proportion between the one and the other, even in

Digitized by Google

the flat district of the river basins here dealt with, may be taken as 10 to 1. Extreme floods occur only at uncertain and distant intervals. During the last thirty years there have been only twelve floods in this district which have done any serious amount of damage, a list of which will be found in Appendix II. Therefore if the channels be made sufficiently capacious to carry off these, they would be far too large for the ordinary discharge, and would become choked with shoals and weeds. The great expense and waste of land which would result from a channel made sufficiently capacious to carry off excessive floods, at once show that any such idea is impracticable.

In river improvement it must always be a matter of consideration whether the advantage to be gained by any particular scheme will be equal to the outlay, and whether it be not better to allow tracts of low-lying land, which are now occasionally flooded, to remain so, than to spend more than the value of their fee simple in protecting them. As pasture land they would always have a certain value, and where the owners have broken up such tracts into arable land, they have done so knowing the risk, and should abide by it.

A careful investigation into the rainfall in the Witham basin of the last fourteen years tends to the conclusion that the height of the floods is not entirely due to the actual amount of rain falling, as much depends on the condition of the land and other circumstances prevailing at the time. Taking the rainfall of Boston as typical of that of the Witham and Welland basins, a fall of 2½ inches in three days in July 1867, only raised the water in the main drains 3 inches, whereas the same quantity, in July 1872, made very heavy freshets in the river, and in July 1880 caused a serious flood. Again, in 1868, although the rainfall for the autumn was heavy and continuous, and 6 inches above the average, yet the water in the Witham had not risen to flood height until the end of December. On the other hand, a fall of 1·66 inch of rain and snow in January 1867 rapidly filled the rivers and flooded a considerable area of Fen lands, although the rainfall for the previous period had not been excessive.

It has generally been the custom in designing fen drainage to allow at the rate of a continuous fall of 0·25 inch of rain during twenty-four hours. This calculation was adopted by Sir John Hawkshaw, Past-President Inst. C.E., in his report for the discharge of the whole basin of the Witham, and also for the large pumping engines at Lade Bank, for draining the East Fen. Sir John Coode, in his scheme for the improvement of the North

Digitized by Google

Level drainage in the Nene, provided for 0·25 inch, although he considered 0·187 inch would be all that would come daily to the outfall. During floods he ascertained that a quantity equal to 0·10 inch over the whole area of 79,855 acres was daily discharged.

During the last few years (Appendix I.), the rainfall in the Witham district, if taken over seven days, would give a daily mean of 0·37 inch, or if over fourteen days, 0·25 inch, the maximum for the seven-day period being 0·63 inch, and for the fourteen days, 0·34 inch. Although at such times the ground is fully saturated, and in an exceptional condition, it is not possible that the whole of the rain which falls could be delivered at the outfall. The mean discharging capacity of the four rivers is equal to 0·094 inch every twenty-four hours, allowing a velocity of 3 feet per second (about 2 miles an hour).

To adapt the channel to the discharge of 0·25 inch in twenty-four hours would therefore require that they should be made nearly three times their present size, a course which, even if practicable, would render them far too large for all ordinary discharges. Provision for a continuous discharge of 0·25 inch of rain every twenty-four hours would require, with a velocity in the channel of 3 feet per second, a sectional area equal to 1 square foot for every 285 acres, whereas at the present time there is only an average of 1 square foot to every 816·6 acres (Appendix IV.)

The present discharging capacity of the Witham is equal to 0·105 inch of rain in twenty-four hours; of the Welland, 0·096 inch; of the Nene, 0·063 inch; and of the Ouse, 0·101 inch; and this is not sufficient to prevent flooding.

It becomes, then, necessary first to provide a channel for the ordinary discharge of the river, and also for occasional excessive floods. A modification of the system of wash lands, already referred to, points to the method of securing this end. The ordinary channel of a river should be of sufficient capacity to take the normal flow of the stream, the sides being made at as steep a batter as the natural inclination of the soil would allow, and at such a height as may be desirable for retaining the water for the supply of agricultural and domestic purposes or water-power. The water being then retained in as small a compass as possible, the weeds would be less likely to grow and shoals to accumulate. The sides beyond this should be laid at a slope sufficiently flat to allow of the growth of grass and the feeding of sheep and cattle in summer, and the protecting banks set sufficiently far back to allow room for the passage of the greatest floods likely to occur. Where banks already exist, they would require removing on one side at least, and where there

Digitized by Google

are no banks the material dredged and cleaned out of the channel would in many cases be sufficient to form them. Bridges and other openings must of course be adapted to the flood discharge. By this means provision would be secured for both ordinary and flood-water, without loss of productive land, and the varying character of the discharge accommodated.

Where the channel passes through a town, as the Witham at Boston, the Welland at Spalding, and the Nene at Wisbech, the difficulty of altering the river is no doubt greatly enhanced; but it may be overcome in the manner proposed by Mr. Abernethy for Wisbech, by making an entirely new cut for the river, and dockising that portion of the old river which passed through the town. By this means the discharge of the floods would be provided for, and by removing the ships from the channel where they are always an obstruction in floods, they would be enabled to lie and discharge afloat in the dockised channel of the old river at the existing granaries and warehouses.

It may no doubt be urged that the expense of thus altering and adapting a river to meet ordinary flood discharges would be very great, but if the cost was equitably spread over the whole watershed, the tax would not be greater than the advantage gained.

In the upper reaches of the river much flooding could be saved by dredging and cleaning out the present channels, and using the material in forming embankments, provision being made for the lateral drainage by soak dykes or drains parallel with the embankments, and discharging at a level sufficiently far down the river.

Regulation and Storage of the Water.

The regulation of the water requires as much consideration as its discharge. The greater rapidity with which the rainfall is now voided leaves less to percolate through the soil for the supply of wells, springs, and brooks. Flooding is thus frequently followed by drought. The level of the water in the soil is lowered below the depth at which it can rise by capillary action to the roots of the plants, the soil becomes parched, and vegetation languishes for want of moisture, and great inconvenience is experienced from the failure of the water supply from wells and brooks.

In all river improvements the fact should be kept steadily in view, that the rainfall is only to be got rid of after making due provision for water supply, irrigation, water-power and navigation. These are none of them incompatible with good drainage. It is only necessary that proper provision should be made by sluices and

Digitized by Google

weirs for the discharge of floods, and by side cuts or arterial drains where the water has to be held up so high that drainage cannot be obtained for the ordinary discharge.

The value of holding up the water as an aid in the cultivation of the soil is fully recognised throughout the whole of the Fens, as also in Holland. The water in the main and subsidiary drains is maintained in summer at a uniform level of from 2 to 3 feet below the surface, by a system of sluices with doors over which any surplus flows, but which are drawn immediately the supply exceeds the demand, and the water is thus regulated to a uniform level.

Water held up in a similar manner in the higher levels would not only feed the wells but afford power for the working of the machinery of the farms through which it traverses of a far more economical character than steam.

Conservancy.

The administration of a river is hardly an engineering matter; but it is a subject which seriously affects the carrying out of any scheme of improvement. One difficulty encountered by an engineer is the restricted character of the portion of the river he has to deal with. He is called upon to devise a remedy against flooding or other evils in a particular section of a river, the remedy for which can only effectually be found by dealing with portions beyond the jurisdiction of those who have sought his aid. Attempts to bring the various bodies having control over the river into harmony, in order to carry out one comprehensive scheme, almost invariably end in failure from the diversity of interests. Every local scheme is violently opposed by all other interests; and it has been stated on reliable authority that the internecine feuds on the river Nene alone during the last fifty years have cost more than £100,000 in parliamentary and legal contests. The cost of obtaining the parliamentary powers necessary for the improvements of the Ouse have amounted during the past fifty years to upwards of £150,000; and for parliamentary proceedings alone for the Nene Valley Acts over £30,000.

An engineer is thus frequently compelled to design and execute partial works on a section of the river at great cost, where the same amount contributed to a general improvement would have effected tenfold advantage. Thus, on the Witham, within the last few years, a sum of nearly £50,000 has been expended on the middle section of the river in deepening the channel and raising the banks between Boston and Lincoln, without any provision for

Digitized by Google

increasing the discharging power through Boston to the sea, or relieving the lands above Lincoln by enlarging the capacity of the weirs and sluices. This was done in spite of the protest of Sir John Hawkshaw that no effectual relief could be given without extending the works downwards to the outfall in the sea. The consequence of this action has been that the water is brought more rapidly to the lower reaches without being provided with any increased means of escape, and backs up the lateral drains, bringing greater pressure on their banks than they can bear. The floods have been greater in this district since this work was done than they ever were before.

It is only after repeated attempts, spread over the last eighty years, that the various trusts below Lincoln have at length united in a common scheme for the improvement of the outfall from Boston to the sea. Provision is also about to be made for the better discharge of the water from the river above Boston, but even now this will give little relief to the city of Lincoln and the lands above.

The same process took place on the Nene. A sum of £150,000 was spent in improvements on a section of the river between Wisbech and Peterborough; and the channel was lowered and deepened without providing for the escape of the water to the outfall, the consequence being that the excavation rapidly filled up, and, in spite of this large expenditure and the consequent heavy taxation, no benefit ensued.

In the attempt made a few years ago by the corporation of Wisbech to carry out the scheme for cutting off the Horse Shoe bend through the town of Wisbech—a plan which had been recommended by every engineer who had reported on the matter for the last fifty years—they were defeated by the opposition of other interests in the river, each fearing some damage to the particular section of the river or interest represented.

The number of private Acts of Parliament in force with relation to these four rivers, even only where they pass through the Fen land, is extraordinary. The number of jurisdictions which have control over the river or the banks has accumulated till at times it is almost impossible to define their powers and rights.

The whole history of the Fen-land drainage shows the baneful result of divided administration, and teaches that no voluntary or private legislation is sufficient. The administration of the several districts protected by Fen Acts is most efficient so far as it goes, and some of the schemes in force may well form a model for any Conservancy Act that may be framed. To supersede existing

Digitized by Google

organizations by new boards elected on a different plan would be most injudicious. What is wanted is a consolidation of all these smaller trusts, and the uniting them by representatives sent to one common Conservancy Board, which should have control over the main river and its banks from its source to the sea, leaving the management of the interior drainage to the trusts already in existence, or, where none exist, to others formed under the powers of the Land Drainage Act. Such a system would cause as little disturbance with existing arrangements as is practicable with an efficient system of conservancy of the main outfall.

The communication is accompanied by a large map of the district, from which Plate 6 has been reduced and engraved.

Digitized by Google

APPENDICES.

APPENDIX I.—Basins of the Witham, Welland, Nene, and Ouse Rivers.

Rainfall for twelve years (1869–80).

—	County.	Height above Sea.	Maximum.	Minimum.	Average.
		Feet.	Inches.	Inches.	Inches.
Wytham-on-the Hill	Lincolnshire.	167	32·83	14·40	23·88
Grantham		179	35·59	16·94	25·53
Haydor		..	34·87	14·84	25·52
Boston		24	35·53	18·22	26·02
Stubton		..	36·49	18·76	26·51
Navenby		..	36·14	18·38	26·67
Miningsby		..	33·12	17·90	26·32
Branston		136	35·40	19·07	26·56
Market Rasen		111	30·19	17·76	25·37
Gainsboro'		76	39·83	16·44	23·91
Lincoln		26	32·15	16·29	24·31
Stamford		116	34·59	16·37	25·15
Spalding		20	37·12	16·22	26·10
Hemel Hempstead	Herts.	..	36·28	21·63	28·92
Hitchin		..	30·26	17·76	25·76
Stevenage		..	31·86	18·83	26·74
Stoney Stratford	Bucks.	..	35·08	18·48	27·48
Newport Pagnell		..	33·72	17·94	25·83
Weedon Beck	Northampt'n	..	36·59	17·83	27·67
Northampton		..	36·88	17·21	27·42
Wellingboro'		154	33·40	17·21	26·24
St. Neots	Hunts.	..	31·95	15·62	25·12
Huntingdon		..	33·12	18·22	26·58
Whittlesea Mere		..	34·91	18·51	25·72
Ampthill	Bedford.	..	31·67	17·23	25·09
Biggleswade		..	31·46	16·64	24·45
Cardington		..	31·39	14·87	23·90
Cambridge	..	..	31·50	14·25	23·97
Ely	..	..	29·03	14·70	23·16
Stanground Sluice	..	..	29·24	15·68	22·54
Wisbech	..	..	38·46	19·45	27·11
Brandon	Norfolk.	..	36·26	16·70	26·43
Outwell Sluice		..	33·66	16·04	23·03
Lynn		..	33·30	20·44	27·54
Swaffham		..	40·13	20·69	27·59
Market Harboro'		..	39·47	18·49	29·33
Ryhall	Rutland.	..	36·61	16·46	26·49
Oakham		..	40·34	22·56	28·65
Average		..	34·48	17·39	26·05

Average Rainfall of thirty-eight Stations. Twelve Years, 1869–80.

	Inches.	
1869	26·15	
1870	18·49	
1871	22·42	23·41
1872	33·53	
1873	21·27	
1874	18·60	
1875	29·50	
1876	29·77	
1877	26·92	28·69
1878	26·63	
1879	27·81	
1880	31·54	
Average	26·05	

Digitized by Google

APPENDIX II.—Rainfall at Boston.

Average annual rainfall at Boston respectively for five, ten, twenty, and forty-year periods.

Years.	Five-Year Periods.	Ten-Year Periods.	Fourteen and Twenty-Year Periods.	Forty-Year Periods.
	Inches.	Inches.	Inches.	Inches.
1826–30	22·10	..	22·45	..
1830–35	21·25	21·85	..	..
1836–40	24·50			
1841–45	24·64	24·73	23·25	
1846–50	24·82			
1851–55	20·90	21·78		23·82
1856–60	24·66			
1861–65	19·84	22·22	24·39	
1866–70	24·61			
1871–75	24·09	26·56		
1876–80	29·04			

The period 1861–65 in the above is the driest. In 1864 only 14·94 inches of rain fell. The next driest is 1851–55. In 1854 only 13·79 inches fell, this being the smallest fall known. The wettest period was 1876–80; the next 1846–50, but then the rainfall was 4·22 inches less than in 1876–80. The heaviest rainfall was in 1880, when 35·53 inches fell. The nearest to this was in 1872, when 32·69 inches fell; 1848, with 32·64 inches; 1876, with 31·05 inches; and 1860, with 30·69 inches. These were the only years since 1826, from which period the first records date, that as much as 30 inches of rain fell.

Twenty Years' Average Rainfall at Boston.

Years.	Inches.	Years.	Inches.	Years.	Inches.
1852–71	22·07	1856–75	22·80	1859–78	23·91
1853–72	22·56	1857–76	23·35	1860–79	24·15
1854–73	22·38	1858–77	23·50	1861–80	24·39
1855–74	22·56				

Digitized by Google

YEARLY RAINFALL at BOSTON.

Years.	Inches.	Years.	Inches.	Years.	Inches.
1826	15·43	1845	24·29	1863	18·28
1827	20·27	1846	23·40	1864	14·94
1828	28·59	1847	23·92	1865	25·63
1829	24·14	1848	32·64	1866	25·58
1830	25·90	1849	24·03	1867	25·94
1831	25·87	1850	20·11	1868	25·61
1832	22·55	1851	22·46	1869	27·26
1833	22·62	1852	25·30	1870	18·66
1834	14·66	1853	21·40	1871	23·81
1835	21·87	1854	13·79	1872	32·69
1836	21·38	1855	21·57	1873	20·21
1837	23·58	1856	19·49	1874	18·22
1838	18·95	1857	23·17	1875	25·55
1839	28·48	1858	19·00	1876	31·05
1840	18·61	1859	20·96	1877	26·14
1841	27·26	1860	30·69	1878	26·77
1842	24·73	1861	20·38	1879	25·72
1843	25·29	1862	19·98	1880	35·53
1844	21·64				

AVERAGE MONTHLY RAINFALL at BOSTON.

Years.	January.	February.	March.	April.	May.	June.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1850–59	1·46	0·95	1·16	1·42	1·35	1·90
1860–69	2·00	1·41	1·72	1·87	2·08	1·91
1870–79	1·72	1·78	1·29	1·89	1·77	2·25
1879–80	1·48	1·95	1·32	2·70	2·15	2·86

Years.	July.	August.	September.	October.	November.	December.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1850–59	2·61	2·40	1·86	2·54	1·85	1·22
1860–69	2·28	2·39	1·96	2·10	1·82	2·37
1870–79	2·53	2·57	2·61	2·03	2·37	2·07
1879–80	2·99	3·01	3·46	2·64	2·39	2·09

Digitized by Google

APPENDIX III.—Table showing effect of Rain in causing Floods in the Witham.

Year.	Month.	Rainfall of Previous		Rainfall Cause of Flood.		Greatest Fall in One Day.	Mean Rate of Fall Spread over		Maximum Height of Flood-water on Sills.				—
									Grand Sluice		Black Sluice		
		Four Months.	One Month.	Inches.	Days.		Four Days.	Fourteen Days.	At High Tide.	At Low Water.	At High Tide.	At Low Water.	
		Inches.	Inches.			Inches.			Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	
1852	Nov.	15·32	4·32	..	..	..	..	..	14 6	..	..	..	Highest known flood to this date.
1857	Jan.	6·38	3·13	..	..	..	..	..	14 7	..	15 9	12 6	
1862	Mar.	6·55	3·22	..	..	..	..	..	13 7	..	16 1	..	
1867	Jan.	13·12	3·67	1·66	10	..	0·19	0·15	14 0	9 6	16 1½	13 9	
1868–69	„	12·90	5·87	7·13	40	..	0·29	0·27	14 0	11 6	16 0	14 3	River full of deposit 11 feet deep against door of sluice.
1872	April	10·16	2·70	2·79	16	1·10	0·17	..	13 10	9 6	16 0	12 5	
1875	Nov.	12·30	4·90	3·13	14	0·93	0·28	0·22	15 6	10 5	16 7	13 9	River in good order.
1876–77	Jan.	13·22	4·26	3·02	14	0·46	0·43	0·21	15 11	11 0	16 9	12 6	„ „
1878	Nov.	10·24	6·94	3·47	17	0·91	0·32	0·24	13 9	12 4	15 9	..	
1880	July	9·03	3·95	4·13	17	1·55	0·39	0·27	11 9	8 9	14 3	12 0	„ „
..	Sept.	13·26	2·42	4·28	4	1·58	0·62	0·34	14 5	10 0	16 3	12 6	
..	Oct.	16·98	4·91	4·44	5	2·79	0·63	0·31	15 0	10 8	17 1	13 0	Greatest rainfall in one day ever known.
Average		..	..	..	..	..	0·37	0·25	..	..	..	..	

Digitized by Google

APPENDIX IV.

Name of River.	Length in Miles.		Drainage Area in Square Miles.	Acres Draining into Upper Reach.	Area of Waterway of Upper Reach.	Number of Acres to Square Foot of Channel.		Number of Acres to 1 Mile of Main Stream.	Number of Acres to 1 Mile of Main Stream and Tributaries.	Tidal Flow in Miles.	Proportion of Tidal to Fresh Water in Upper Reach.	Inclination per Mile of Surface of Stream in Floods.
	Main Stream.	Tributaries.				Upper Reach.	Lower Reach.					
					Feet.							Inches.
Witham . .	89	98	1,063	448,835	660	680	325	7,644	3,635	8	14·60	25
Welland . .	72	65	707	300,000	400	750	377	6,785	3,302	20	6·65	21
Nene . .	99	52	1,055	564,700	500	1,129·5	307	6,822	4,474	34	6·65	10·5
Ouse . . .	156	241	2,894	1,852,160	2,620	707	463	11,872	4,672	40	5·16	9
Totals and Averages	416 456	456	5,719	3,165,695	4,180	816·6	368	8,155	4,015	..	8·01	..
	872		Acres. 3,660,160									

Digitized by Google

(*Paper No. 1835.*)

"The Conservancy of Rivers: the Valley of the Irwell."

By ARTHUR JACOB, B.A., M. Inst. C.E.

ON approaching the important question of River Conservancy, one of the first thoughts that presents itself to the mind is the great variety of characteristics which the careful study of different rivers brings into view. Between the mountain torrent rushing down its rocky bed, and the broad expansive stream flowing calmly over its bed of silt to unite with the ocean, are to be found many and various modifications. The description of a river of one class, therefore, will serve but imperfectly if applied to others, and for this reason it appears desirable, whilst considering what are known as the "Fen rivers," that reference should be made to a river like the Irwell, which presents many features non-existent in the Witham and the Nene. It is therefore hoped that a brief relation of the characteristics, both natural and artificial, of the river Irwell (Plate 7) may be of interest to the Institution.

The term River Conservancy has been defined to comprise a considerable number of objects:—(1) The preservation of a stream for domestic, sanitary, and industrial purposes, by preventing pollution and interference of other kinds; (2) its maintenance and regulation for navigation; (3) the culture and preservation of fish, and (4) finally, the effectual drainage of the district through which the stream pursues its course, including the abatement of floods. That branch of conservancy which involves the principal natural function of a river, namely, the effectual removal of surface water, is now beginning to press upon the mind of the public, and it may be regarded as pretty certain that before long the Legislature will introduce some comprehensive measure to facilitate the management of the rivers of this country, with the object of preventing the damage and loss occasioned almost annually by the submergence of extensive areas of urban as well as rural property.

By many fairly competent authorities it has been announced that the tendency to flooding has increased of late years, from natural, as distinguished from artificial causes, but there does not appear to be much ground for such a conclusion. There is no difficulty in understanding that during one year or group of years

[1] The discussion upon this Paper was taken together with that upon the preceding one.

Digitized by Google

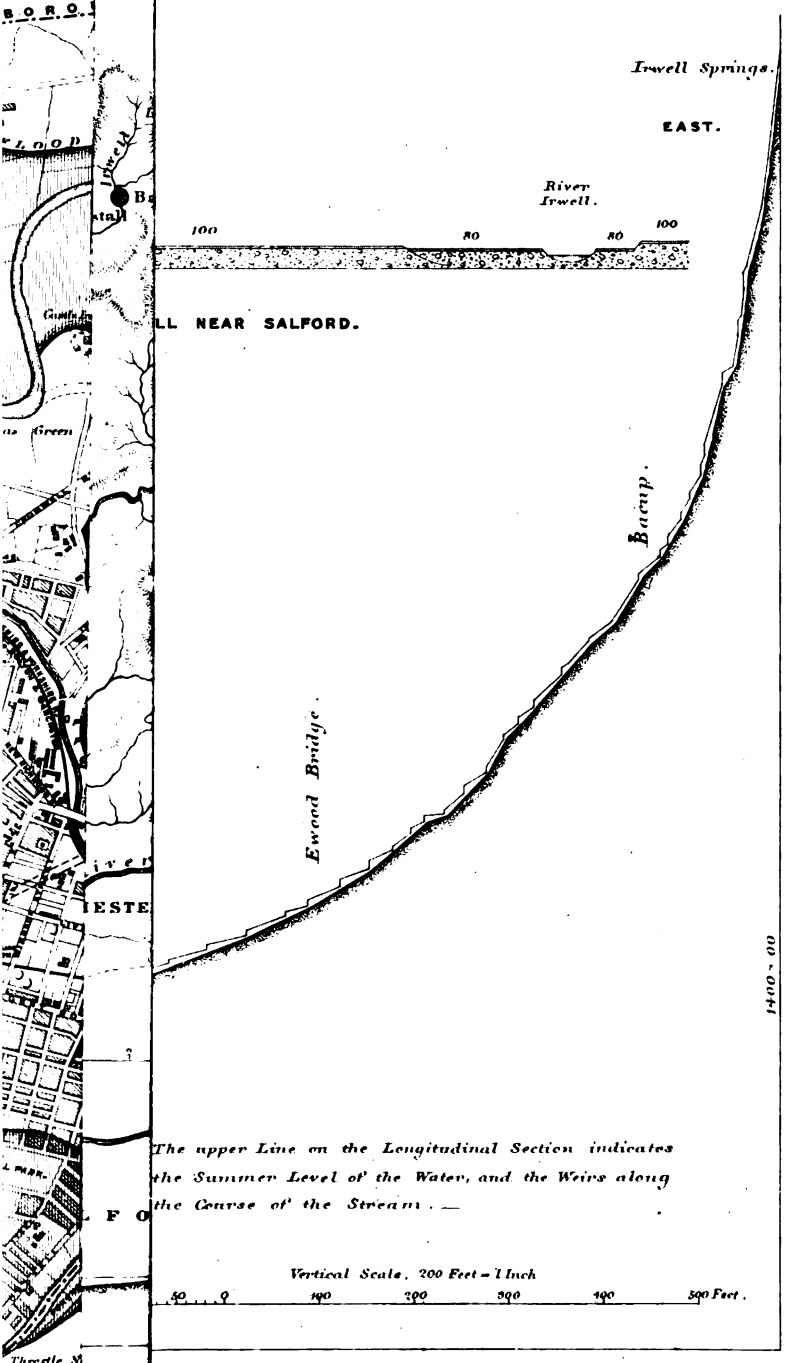
an exceptionally heavy rainfall has occurred, or that an unusually violent downpour has taken place over a large tract of country; but taking one season with another, there is no reason to conclude either that the annual rainfall has increased in volume, or that its descent is less uniform now than it has been heretofore. The fact is often lost sight of that most rivers are subject to flooding, and have been so from prehistoric times. Such streams as have an extensive watershed, with a high declivity in the upper reaches, passing into a comparatively flat inclination as they approach the estuary, are almost invariably subject to sudden floods; and in illustration of this, it is purposed to direct attention to the physical features and causes which have from time immemorial operated to cause floods in the river Irwell.

The river rises about 1½ mile north of the town of Bacup, in Lancashire, 1,325 feet above the mean sea-level. The stream has its origin in the Erewell spring, and during the upper part of its course descends with torrential violence after heavy rain. At Rawtenstall, a distance of about 6½ miles further down, it receives, besides certain minor streams, the Limey water, after which it runs nearly due south to the town of Bury, 3 miles below which place it receives the important tributary, the Roch. Pursuing its tortuous course generally towards the west, the Irwell is again augmented, within a short distance, by the river Croal, which passes through the town of Bolton; and, after its junction with this stream, the Irwell changes it direction and runs a south-easterly course towards Salford and Manchester.

This part of the river is much more direct, and is less tortuous, than any reach of equal length either above or below. The longitudinal section (Plate 8, Fig. 1) is taken along the bed of the stream, and shows the rapidity with which the inclination of the channel increases towards the source.

So rapid an inclination is attended with considerable erosion of the bed, and the quantity of silt carried down by the stream is great as compared with the volume of water discharged. The valley of the stream, which, above Clifton Junction on the Lancashire and Yorkshire Railway, is comparatively narrow and precipitous, widens out, and at Agecroft there is to be found, in the level plains and terraces, geological proof of the natural tendency of the river to flood its banks. The section exhibited (Plate 8, Fig. 2), which has been borrowed from the Records of the Geological Survey of Great Britain, is a cross section of the river valley taken near Agecroft, and shows the way in which the stream had, before the accumulation of glacial deposit, denuded

Digitized by Google

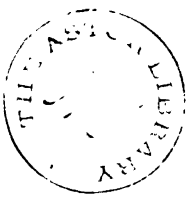


The upper Line on the Longitudinal Section indicates the Summer Level of the Water, and the Weirs along the Course of the Stream. —

Vertical Scale, 200 Feet = 1 Inch

50 . . . 0 100 200 300 400 500 Feet.

Digitized by Google



Digitized by Google

the New Red Sandstone which underlies its bed, having scoured away the rock and formed a valley. During the progress of this operation it is probable that the whole district was at a higher level than at present, and that, becoming depressed, the surface of the country generally was covered by glacial clays and gravels. The general level was again raised, and the stream afterwards scoured away the glacial clays, depositing its silt at the different levels indicated by the surface of the terraces. The upper terraces are no doubt the oldest, and the stream has gone on cutting them away, overflowing its banks, and forming nearly level plains as far as the silt-bearing water reached.

As the stream follows its tortuous course through the Salford district the same physical features are present, namely, a denuded valley underlying a plain of alluvial deposit, and a gradually diminishing inclination in the channel towards the estuary.

The area of the watershed of the river Irwell is 311¾ square miles, and the area of the Mersey occupies 606 square miles. Both streams are tortuous. The direct distance from the source of the Irwell above Bacup, to its junction with the Mersey at Irlam, is 22 miles; but the actual length measured along the river bed is 50 miles. The mean inclination of the surface of the country at the source of the river is 540 feet to a mile; a few miles south, the mean surface inclination is 380 feet to a mile, and in the district immediately above Agecroft—the point where flooding usually commences—the surface inclination is reduced to 340 feet to a mile. These inclinations are measured perpendicularly, or nearly so, to the axis of the river, and being the steepest declivity in the immediate neighbourhood in which they have been taken, represent the slopes at which surface water would descend into the brooks which feed the river proper.

The inclination of the river being the most gradual natural fall within the area of the watershed, presents, of course, a much less declivity than the average surface inclination of the ground. At Bacup the mean declivity of the stream is 176 feet to a mile; between Bacup and Bury the fall is 36 feet to a mile, and immediately above Agecroft the bottom slope is diminished to 8 feet in the mile. As the stream enters the borough of Salford the valley widens, and the inclination of the river bed is reduced to 4 feet to a mile.

It is needless to remark that the variation in the amount of rainfall over a watershed, differing in level as that of the Irwell does, is considerable. At Haslingden, one of the higher stations,

Digitized by Google

the average annual rainfall is nearly double that at Manchester, whilst all the other stations show an excess somewhat in proportion to the altitude.

The following Table, which has been collated from Mr. Symons' Record of British Rainfall, shows the mean annual rainfall of Salford and other prominent stations in the valley of the Irwell, and also the amount of rain which fell at these stations immediately before and during the exceptional floods which occurred on the 16th of November, 1866, and the 23rd of December, 1880.

Station.	Mean Annual Rainfall.	Rainfall on the 16th Nov. 1866, and three preceding days.	Rainfall on the 23rd Dec. 1880, and three preceding days.
	Inches.	Inches.	Inches.
Salford	35·67	No record.	2·75
Bolton	48·00	3·20	2·00
Belmont	59·00	3·90	2·40
Rochdale	43·22	2·13	3·18
Bacup	58·60	No record.	2·77
Rawtenstall	57·50	„	2·88
Haslingden	67·70	„	2·80

The Irwell, like most rivers, is not sensibly affected by sudden and short falls of rain occurring after a season of comparative drought, for before any considerable volume of water can find its way to the river, the surface soil, which for a large portion of the area is sandy, must be saturated.

It is difficult to determine with exactitude the relation between the times of highest flood in the river and the period of maximum rainfall over the watershed, but the observations of the Author show that, when heavy rain commences to fall in the valley, and the ground has been previously moistened though not saturated, the volume of the river becomes visibly affected in about four and a half hours; and similarly it has been found that the abatement of some of the higher floods has commenced at the end of the same interval of time after the cessation, or measurable diminution, of the rainfall in the watershed above. For this reason when the river is in flood, or a flood is expected, pretty reliable information is obtainable by telegraph from Bacup and other places within the watershed.

Digitized by Google

On the 16th of November, 1866, there was a general flood over England, and it was then that what is known as the great flood occurred in Salford. The discharge of the river above its junction with the Irk was 24,000 cubic feet per second. This volume flowed off an area of 135,500 acres, or in other words, about 18 cubic feet of water per second passed away during the height of the flood for every 100 acres of gathering ground.

The natural tendency of the river to overflow its banks has been considerably increased by the want of any efficient system of conservancy in years gone by. The banks of the stream, and of the Croal, the Roch, the Tonge, and other affluents, are occupied by works of different kinds from one end to the other. These works have, for a long series of years, discharged polluting matter of every description into the stream, and the quantity of cinders and other solid refuse which has been got rid of in this way, and without the slightest regard for the interest of the riparian owners lower down the stream, is beyond computation. No great harm has arisen in the steeper reaches of the river, because the current, during even moderate freshets, has been sufficiently strong to wash the refuse down to Manchester and Salford.

In 1869 the Rivers Pollution Commission instituted an exhaustive inquiry into the condition of the Irwell, and reported at that time that "throughout almost the whole course of the various streams which here pass over the weir, not only has the water been polluted from both house and mill by waste matters more or less in solution or suspension, but the river bed has been obviously made the recipient of furnace ashes, waste from spoil heaps of various kinds, and even earth removed in digging house foundations."[1]

This system of depositing cinders and other refuse in the river, or rather laying it on the bank below flood-level to be washed away during the winter, prevails to an extent most discreditable to the manufacturers along the stream and its affluents, but the evil has of late years been somewhat lessened owing to the assiduity of the Corporation of Salford, and the Bridgwater Navigation Company, who watch the manufacturers along the river very closely.

The Corporation are, as a matter of course, interested in preventing pollution of all kinds, but unfortunately their powers are limited, and they can only succeed in securing the conviction of offenders when they are able to prove the introduction into the stream of solid matter in an absolutely insoluble condition.

[1] *Vide* First Report of the Rivers Pollution Commission (1868). Mersey and Ribble Basins, p. 10.

Digitized by Google

There is ample evidence that the refuse which comes down from the higher reaches of the Irwell, and from its tributaries, the Roch, the Croal, the Bradshaw Brook, and other streams, continues to lodge in the flatter parts of the stream, and by raising the bed of the river throughout its course through Manchester and Salford has increased the injurious effect of floods. The Bridgwater Navigation Company spend large sums annually on dredging out the silt, and the material which the manufacturers send down. After a high flood, on the 23rd of December, 1880, the traffic on the Irwell had to be suspended, and several months were occupied in dredging, so as to render the river sufficiently deep for navigation.

It will be thought that the stream during an excessive flood would of itself move the silt deposited in the bed of the river, and create shoals of sufficient magnitude to obstruct the navigation. No doubt this is a reasonable conclusion, but the injurious effects caused by manufacturers always manifest themselves by the quantity of dark suspended matter which passes down during the early part of every flood. This material (the refuse from works) remains deposited above the weirs and in the flatter parts of the stream above Salford for want of sufficient velocity of current to carry it on, but as soon as the speed of the current is increased it is borne forward to form shoals in the stream and injurious deposit on the land adjoining. After the first hour or two of the flood the water becomes comparatively clear, showing that the manufacturers' refuse, which is no doubt lighter than ordinary sand or disintegrated rock, has been successfully removed.

Prior to the year 1862 there does not appear to have been any adequate appreciation in the minds of the Manchester or Salford authorities of the injury that was being done by encroachment upon the river channel as it passed through these towns. The stream, which must in its natural state have had an average width of not less than 120 feet, has been narrowed in several places to 78 and 80 feet, completely throttling it, and increasing to an injurious extent floods that would otherwise pass off without inconvenience or damage. In 1862 the Salford Corporation obtained an Act which enabled them to prevent encroachment on the river channel beyond certain limits then laid down, and much good has been effected by this reform. If these encroachments on the stream cannot be regarded otherwise than with dissatisfaction, at least some consolation is to be derived from the fact that they only intensify in some degree the floods which otherwise might have passed away with but little inconvenience or loss to

Digitized by Google

the inhabitants of the district. If the river had been carefully maintained of a width of 100 or 120 feet, with an average depth during flood of 20 feet, no doubt, though the district would still be liable to floods, they would not have occurred so frequently as they now do. In the flood of November 1866 the discharge below the junction of the Irk was not less than 28,000 cubic feet a second. To carry such a flood as this away without overflowing its banks, a rectangular channel 150 feet wide, 20 feet deep, and with the inclination which would be available if all obstructions were removed, would hardly have sufficed.

There are certain weirs on the river to which it is usual to attribute the flooding, and which no doubt produce some elevation of the surface of the water locally; one of these is situated at Douglas Green, but it is productive of little or no injury, as floods seldom overtop the banks of the stream above. The second weir, proceeding down stream, is at the Adelphi, where the river doubles back, forming a long loop. This weir, which is 7 feet high, would no doubt produce an appreciable elevation during floods in its immediate locality, and for a short distance up the river, if the water were kept between the river banks, but during the greatest known floods the difference in the level of the surface above and below the obstruction was scarcely measurable; in fact it would have been impossible for any one not familiar with the locality to discover the actual position of the weir with only the surface level of the water to guide him, as the water of the river which overflowed the banks for a considerable distance above the weir formed an extensive lake, backing up to the lower side of the weir.

Some persons, not recognising the tendency of all rivers similar in character to the Irwell to flood their banks, are wont to attribute to this weir almost the whole of the evil from which the borough suffers; and at one time the owners were approached with a view to its removal, but the claim was so heavy that negotiations had to be closed. The Throstle Nest Weir, 4 miles lower down the stream, produces a net rise during dry weather of 9 feet 9 inches. The navigation of the river up to Manchester renders a weir at this point necessary, but there is no doubt that if the Bridgwater Navigation Company kept the channel dredged to a sufficient depth a weir of considerably less height would give the necessary depth for navigation.

The Throstle Nest Weir has an interest connected with the early history of engineering in being the means of supplying power to the old paper works, to see which James Brindley, when he was

Digitized by Google

an apprentice, walked from Macclesfield and back again, and as being situated close to the "Bull" Inn where he lived when engaged in constructing the Duke of Bridgwater's Canal near Manchester.

There are other weirs lower down the stream, all tending to raise the level of high floods and to accumulate deposit above them, but their effect upon the height of the floods has been much exaggerated. During the discussion in 1880 on a Paper by Mr. Vernon-Harcourt, M. Inst. C.E., "On Fixed and Movable Weirs,"[1] there appeared to be considerable diversity of opinion as to the question whether fixed weirs had or had not the effect of arresting the onward flow of silt down the stream; and regarding this it may here be of interest to say that the sections taken along the bed of the Irwell show beyond doubt that the erection of the weirs has been followed by the deposition of silt above them. The surface of the deposit is somewhat uneven, owing no doubt to eddies and bends in the stream, but the general level presents a much more gradual declivity than the proper bed of the stream.

That the natural defects of the river, combined with the artificial encroachments upon it, have produced, and will continue to produce, most disastrous results, is unquestionable. The flood of December 1880 submerged about 300 acres of ground almost entirely covered with dwelling houses. The streets were from 1 foot to 3 feet under water, and the basements of all the cellared houses were filled with the foul mud-bearing water of the Irwell. All the manual and team labour that could be collected had to be applied to remove the filth from the streets and cellars before active decomposition should set in. Fortunately, a severe frost occurred immediately after the flood, and the evil effects which were anticipated were providentially warded off. The flood of November 1866 covered, in Salford, not less than 1,100 acres of ground, forming an extensive lake, over the districts of Lower Broughton and the Adelphi, which, it will be seen from Plate 8, Fig. 3, was throttled at its outlet by encroachments on the river channel. The water passed over the banks of the stream between the points A and B, and following an easterly direction filled the whole of the shallow valley almost as far down as the junction with the river Irk, to a depth varying from 2 to 7 feet, and the whole of Peel Park, and the adjoining meadows at the west side of the river were flooded to a depth of 7 feet. It is needless to dwell upon the severe

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lx., p. 24.

Digitized by Google

suffering and loss which this disaster produced; both have been so deeply impressed upon the memory of the inhabitants that every rising of the river is regarded with the keenest apprehension. The flooding was not less extensive below Manchester and Salford; the sides of the stream for an average width of 500 yards were flooded as far as the junction with the Mersey, and this river also inundated completely the valley through which it passes. Below the junction of the Mersey and the Irwell to Warrington, and for some distance lower down stream the flood continued; so that it is not too much to say that the whole of that length of the valley, a distance of 25 miles, presented one continuous sheet of water moving on towards the outfall at Runcorn. This flood was immediately followed by meetings of the corporations and the landowners, as well as the smaller property owners affected, and it was determined on all hands that the flooding of the river must be stopped once for all. Nothing, however, was done. The landowners, the very persons who would receive the most direct benefit from the abatement of the flooding, appeared to lose all interest in the subject when the question of cost came to be considered. The Corporation of Salford were prepared to carry out the necessary works for the relief of their district, and the Manchester Corporation offered a substantial contribution towards the expense, but no satisfactory understanding could be arrived at with the owners, whose land it was proposed to rescue from disaster and improve in value. To have carried out the necessary works, the immediate effect of which would be to enhance the value of all the low-lying land, at the expense of the rate-paying public, was so manifestly inequitable that it could not be entertained; and it is only now in view of some general measure of legislation that the sanitary authority of Salford is able to contemplate with satisfaction, and some hope of a successful issue, the urgent question of the river improvements.

The most eminent advice was taken soon after the great flood of 1866. Mr. Hawksley, Past-President Inst. C.E., reported to the Salford Corporation, pointing out the remedial measures to be adopted. Mr. J. F. Bateman, Past-President Inst. C.E., reported for the Corporation of Manchester; and the late Mr. Cawley, M.P., then a member of the Salford Corporation, also brought his abilities to bear on the question. Between these three authorities there were certain differences of opinion, chiefly with regard to matters of secondary importance; but there was one conclusion common to all the reports, namely, that the existing river channel could not, short of an enormous outlay, be rendered, either by dredging

Digitized by Google

or any other expedient, sufficiently capacious to accommodate maximum floods, and that the only remedy for the evil was to abstract, and lead away from the river, about one-third of its maximum flood discharge. Opportunity offered, two years after the great flood, to measure the actual quantity which the river channel could be relied upon to carry away without overflowing, and it became obvious that any surplus beyond this amount must be removed by an artificial channel to some point south and west of the borough.

It has been suggested that the construction of an artificial channel from the north to the south side of the district would have the effect of increasing the flooding of the river as it passed through those districts situated lower down the river than Manchester and Salford, but this opinion does not appear to be based on sound reasoning. If the river were flowing past Mode Wheel in full flood, and an artificial channel from point D to point C at the Adelphi were suddenly opened, no doubt the flooding at Mode Wheel would be greatly augmented; but with proper management an artificial relief channel would not necessarily have the effect of increasing the discharge below its outfall. Let the effect which it would produce, during a short but violent flood, be first considered. Suppose the river to be embanked down to the point C, so as to keep the whole discharge within the channel to that point, and a tunnel to be constructed thence to any point D below Manchester and Salford. At the commencement of a flood, sluices at the head of the channel opening down to the bed of the river could be opened, either automatically or by mechanical agency. Thus for the early part of the flood the artificial channel would be used instead of the river proper, and, so long as its capacity sufficed for the work to be done, no water would pass down the natural bed of the river. It is true that the first part of the flood, being delivered through a channel of uniform section, of shorter length, and of higher inclination than the bed of the river, would reach the point D sooner than if the water had passed along the natural bed of the river, which is longer than the suggested tunnel in the ratio of 10 to 3; but this would pass away in detail, and without doing any damage; practically prolonging the flood in point of time, and distributing the water to be discharged over a longer period than if the tunnel had not been brought into use. The distance from C to D is 1½ mile, and the measured distance round the river channel is 5 miles, so that the water which did not pass through the tunnel would take about forty minutes longer to reach the point D than if it had passed through it.

Digitized by Google

The discharge would, in short, commence forty minutes sooner at D, and the period of flood would be lengthened by that amount. Thus the injurious effect for a short flood would be diminished at every point below C. Suppose, however, that the flood continued for several hours, the earlier part of it would be delivered through the artificial channel, and be carried down the stream below D without harm. As the flood continued to increase, the water that could not pass down the channel would flow along the natural bed of the stream until it reached the point D, where the discharge from both channels would unite; and if due protection were not provided from that point downwards, by embanking or otherwise, flooding would occur; though it would not be increased in any way by the artificial channel, for, whether the water flowed down the old or the new channel, or through both together, no more could pass the point D during a given time than the flood was capable of delivering. Thus it appears evident that the objections urged against artificial cuts are illusory, and likely to lead to an erroneous conclusion. This point is only referred to here in order to show that the remedy suggested for the relief of Manchester and Salford is a practicable one, and not calculated to inflict injury upon the districts situated lower down the stream.

The mode of treating a river to prevent it from flooding must necessarily vary with the locality and special circumstances. Through agricultural districts the cheapest and most easily applied expedient is embanking; but this can rarely be resorted to in towns, and where the stream has been encroached upon so as to render flooding inevitable, no alternative remains but the construction of an artificial channel to carry surplus waters round or clear of the town.

In addition to the recommendations made from time to time that the stream should be relieved by an artificial cut, the deepening of the channel by dredging and scour have been suggested, as well as the embanking of the river sides where it passes through open ground. With a moderate outlay on side embankments the river could, without difficulty, be kept within its channel, and if in addition to controlling the stream in this way the bend below Douglas Green were cut off, and suitable sluices constructed at B, the improved inclination would speedily deepen the channel. It has been remarked in general terms that in the improvement of rivers the cardinal point to be kept in view is the increasing of the hydraulic mean depth of the channel, and embanking will secure this object in a less expensive way than any other.

The removal of weirs is a desirable object, but as a rule t

Digitized by Google

is no necessity, whilst improving a river, to deprive riparian owners of such water-rights as they may have fairly acquired by time and right of user. Side sluices can without difficulty be constructed, or the weirs can be provided with opening bays which can be worked either by manual or hydraulic power, when floods occur. By such means interference with vested interests may, to some extent, be avoided, and those exorbitant claims set aside which so frequently compel administrative bodies to abandon works of improvement of the utmost importance.

Water power on a river like the Irwell, which is usually either high or very low, possesses but little value. The greatest known discharge of the river reached 28,000 cubic feet per second, but the stream sometimes dwindles down to a volume not exceeding a few cubic feet per second, and in a few days after a heavy fall of rain, producing a freshet in the river, the discharge is so low that there is hardly sufficient water to float a small skiff.

Whilst considering the several means that might be adopted for controlling floods in the Irwell, compensation reservoirs have not been lost sight of. It might at first appear easy to embank the valley above the flooded district so as to receive all the water in excess of what the channel is capable of discharging; but a very simple computation shows that the plan of impounding is unsuitable in such a watershed as that of the Irwell and its tributaries. A flood of ordinary duration lasts from ten to twelve hours at its highest level, and as there would be an excess in great floods of at least 8,000 cubic feet per second above what the channel is capable of discharging, it would be necessary to provide a reservoir to hold this quantity. Such a reservoir, with an average depth of 20 feet, would have a superficial area of about $\frac{3}{4}$ square mile, and would occupy a much greater extent than this of valuable agricultural land; but the land would be the least expense to be met; mills and works of all kinds on the margin of the river would have to be purchased, railways, roads, and canals to be diverted, and altogether the outlay would be so formidable as to render the construction of reservoirs in the valley of the Irwell out of the question.

Any communication treating on the subject of River Conservancy in its purely technical details, without reference to the all-important question of the constitution and election of the authorities which are to direct the execution of work and to control expenditure, would be but imperfect, and it will therefore be necessary to consider briefly some of the leading principles which should be kept in view in defining conservancy areas, and determining the powers

Digitized by Google

of Boards to rule over them. In almost every case where River Conservancy Boards have been formed, their control has been limited to a certain well-defined area along the margin of the river, and they have found themselves unable to cope with many evils which, though arising beyond the limits of the district under their jurisdiction, contribute to the production of those conditions which it is the interest and the desire of the conservators to alter. Not to enumerate other matters, sewage pollution, and the discharge of manufacturing refuse are allowed to pass freely into tributary streams, and finally into the main watercourses of the country, and such offences are wholly beyond the control of conservancy bodies. This being so, the only remedy is to make the watershed, or a large section of it, the conservancy district.

The rights of private persons in respect of water and of easement are well defined in all ordinary cases. If any owner interferes with a stream, either by adding to or taking from its natural volume, so as to inflict injury upon his neighbours, there is no difficulty in compelling him to make reparation for the damage done. The fixed principle is that the stream may be lawfully used so long as others who enjoy the use of it are not prejudicially affected. It is only necessary to enlarge this principle sufficiently, to show that almost every owner of property within the watershed of a river has a certain responsibility cast upon him in respect of that river, and that in using his property he may be instrumental in modifying the discharge of the stream by increasing it, diminishing it, or polluting it.

The natural surface of the ground retains a portion of the rain which falls upon it, such a quantity, in fact, as would, in many instances, be sufficient, if not absorbed, to cause flooding when it reached the river. If, then, the construction of roads and streets, the building of houses, paving open spaces, and facilitating the escape of rainwater generally has the effect of discharging the whole of the rainfall, instead of a part of it; and if, in addition, impervious sewers are constructed to hasten the delivery of storm waters into such rivers as are liable to flooding, there can be no question that the ordinary operations of building, paving, and draining actually inflict injury upon those whose property is situated in the lower reaches of the stream. Again, agricultural operations can hardly be carried on without the watercourses of a country being affected. It is still a question whether the operation of under drainage really has a tendency to facilitate the delivery of surface waters to a river. Evidently a layer of soil 3 or 4 feet in thickness, which has been thoroughly under drained, will be in

Digitized by Google

a more absorbent condition than soil which, for want of drainage, is in a sodden and damp condition. The soil which has been drained will absorb water more rapidly than the other, but on the other hand when the water so absorbed has passed through the surface it will escape into the ditches and watercourses, and so into the rivers, more rapidly than by springs or other natural outlets. The operation of under-draining usually involves the deepening and regulating of ditches for the escape of the waters; and in short it is the object of every careful agriculturist to get rid of surface water as fast as he can, and in one way or another he succeeds in his object. If, then, town and highway authorities, owners of house and agricultural property, manufacturers and others, contribute in any degree to the flooding of rivers, they should be prepared to submit to taxation in their due proportion, for the expense of mitigating and controlling floods in the river, which it is their right to use in common with others. If such a mode of reasoning be sound, and if upland authorities and owners are concerned or liable to taxation, it is clear that they should be represented on any conservancy board that may have charge of a river, and in order that this may be accomplished, it appears only reasonable that the watershed of a river, which is usually a well-defined area, should constitute the conservancy district.

The attempt to deal with rivers piecemeal, each authority along the stream having control of a limited extent, could not possibly result in any useful or concerted action. It appears to be the nature of small local authorities to regard their neighbours with distrust and jealousy, and so difficult a matter is it to bring two neighbouring authorities into harmony for the accomplishment of a common object, that any one who has tried to do so will regard the uniting of a considerable number as hopeless. River works are usually large in extent and costly, and are of such a character that a mode of treatment in sections would be both expensive and troublesome, and under certain physical conditions it would often be impossible to do anything effectual to prevent the recurrence of floods, without carrying out works in one or more of the adjoining districts. Conservancy areas should therefore be large, and no better definition of them can be found than the watersheds of rivers, where they are of moderate size.

The system of conservancy pursued on the continent of Europe, though not suitable to England or English political principles, may be glanced at with some interest. In Prussia, Bavaria, and Saxony

Digitized by Google

the State authorities assume entire control of the main and navigable rivers, defraying the expenses of their management out of tolls collected from those using the stream for navigation, mill power, or other purposes. They claim absolute ownership in the waters, and prevent any interference even with tributary streams. In most cases the riparian owners are enabled to combine for the purpose of protecting themselves by embanking out rivers which adjoin their property. Several owners or even townships can combine, and on application to the Government of the State are constituted the conservancy authority; they are armed with powers to compel those who fail in their duty to construct the necessary protection works or to maintain them. They are further authorised to tax all who are benefited; but have no power to impose dues on persons occupying land situated out of the reach of floods. In some instances the State contributes a portion of the cost of protection works, where such works have the effect of improving the land and increasing its rateable value, on the principle that such increase is a source of profit to the State. The State also sometimes grants pecuniary aid to townships, and if it becomes evident that nothing will entirely cure the evil of flooding but a diversion of a part of the water by the construction of an artificial channel, the State, in virtue of its property in the water, executes the work gratuitously; and again, if it is found necessary to erect embankments along a stream to maintain the navigation, even though the flooding of land belonging to private owners is prevented by such a work, the State usually defrays the cost of the undertaking out of the public exchequer.

The system of conservancy in France is somewhat different from the German system. The French Government has always undertaken the conservancy of navigable streams, and has to some extent recouped itself from the navigation dues and other charges; but lately taxation of this kind has been abolished, and the Government exchequer is now chargeable with all expenses connected with the conservancy of rivers. The embanking of lands for the preservation of floods is carried out by syndicates, of which there are two kinds. Free syndicates, which are associations of such adjoining owners as desire to protect their property from the incursions of a river, but these societies have not succeeded to the extent that might have been anticipated for want of unanimity amongst themselves. Authorised syndicates, which are endowed with greater powers than the free associations, and can compel the minority of landowners to fall in with schemes projected for the relief of the district.

Digitized by Google

The mode of electing Conservancy Boards for England will become a matter of the first importance if any useful result is to follow legislation upon the subject of rivers. All who are to be taxed, whether upland or lowland owners, must have a voice in the representation of the district, and it will require a very judicious balancing of interests to ensure that any real work shall be done. The Bill introduced last session of Parliament was only permissive in its operation, and there is no difficulty in understanding that a Conservancy Board formed under the powers conferred by such a Bill might, unless compelled by pressure from without, continue in a state of apathy, or rather studied inaction.

It is quite conceivable that the representatives returned by the owners of property, in any district not injuriously affected by flooding, might predominate in numbers and effectually bar the way to the execution of works, and place their veto on all expenditure of money from which they or their constituency would derive no direct benefit. It would therefore appear to be urgently necessary that any Conservancy Act which may be passed should contain ample provision for interference on the part of the Local Government Board, if it should be satisfactorily proved that the conservancy authority has failed, either wilfully or through apathy, to discharge the duties entrusted to it.

This communication is accompanied by maps and sections, from which Plate 7 has been prepared.

Digitized by Google

Discussion.

Mr. ABERNETHY, President, said he trusted the discussion would not be of a limited character, and that questions affecting navigation as well as the prevention of floods would be taken into consideration. The latter subject had occupied the attention of Government for some time, and no doubt would be further considered during the next session of Parliament; and the practical remarks which members of the Institution might make, as the result of their experience, would probably aid in promoting proper legislative measures. Mr. Abernethy

Mr. WHEELER wished to add that the object he had in view in writing the Paper was to call attention to the fact that the watershed there described was the easiest in England to deal with from an engineering point of view. Upwards of £2,000,000 of money had already been expended in improving the Fen rivers; but all the engineering works were unsatisfactory in consequence of the divided jurisdiction. Until some alteration was made in the law, and the rivers were put under one general administration, no works that engineers carried out would produce a satisfactory result. Mr. Wheeler.

Mr. JACOB remarked that the area flooded during the great flood in Salford in 1866 was shown in Plate 8, Fig. 3. It would be seen that as the river approached the higher reaches, it became steep and that there was no flooding. The flooding began a little below Agecroft; it then passed down and covered the urban portion of Salford close to A and B, and flooded 1,100 acres of the urban district. Then it followed down to the junction with the Mersey, and a very similar state of things continued to Warrington. The two members of the Institution, who had advised the Corporation, had suggested certain tunnels; but he had taken the tunnel, C to D, as a mean position between them, in order to illustrate the principle he had tried to establish in his Paper, that tunnels did not have the effect of flooding the district below where the works were carried out. Mr. Jacob.

Sir JOHN COODE was inclined to regret that the second Paper had been introduced, because the four rivers mentioned in the first were of a special type, altogether of a peculiar character, and, he thought, would better have been treated by themselves. A remark in the early part of Mr. Wheeler's Paper might lead to the inference that there was a doubt among engineers accustomed to deal with subjects of this kind as to the principles which should guide them, but he believed that there was no doubt whatever. The principles Sir John Cood

Digitized by Google

Sir John Coode. were very well known; and each case, keeping those principles in view, must be dealt with upon its merits. Mr. Wheeler had referred to a peculiar throttle in the Nene at Wisbech. Any one who cared to look more particularly into the subject would find that circumstance fully detailed and illustrated in a Report of his own to the Duke of Bedford dated November 1874.[1] The throttle was of a remarkable character. Mr. Wheeler had described it in a very few words: "Thus the particular tide observed ebbed three and a quarter hours at the lower end of the trained portion of the channel before it had reached the 'Dog in a Doublet,' 25 miles above, and then continued flowing there for forty-five minutes. The water rose 6 feet at the upper end, while it fell 6 feet 11 inches at the lower end." The mere statement of that fact would show that this part of the river was in a very abnormal condition. The remedy proposed was one which had been put forward ever since the year 1769. It was recommended by Messrs. Yeoman in 1769; by Mr. Edwards in 1771; by Mr. Rennie in 1814; by Sir John Rennie in 1840; by Mr. Robert Stephenson in 1848 and 1858; by Mr. George Robert Stephenson in 1858; by Mr. Page in 1860, and by Mr. Abernethy, President, in 1877. He believed that the proposal to make the cut was based upon sound principles; but he went further and said, that although it had been twice placed before Parliament, it had never been put forward in such a shape that the committee had been satisfied that legislative effect should be given to the proposal. The principle was sound, but at the same time several important interests would be affected by it. When it could be put forward in such a shape as would make due provision for meeting all those rights and interests, no doubt Parliament would sanction it. With regard to the formation of reservoirs, he thought Mr. Wheeler had effectually disposed of the idea of attempting to diminish floods by the formation of reservoirs along the course of a river. Mr. Wheeler had called attention to the conditions which created flooding. Sir John Coode entirely agreed with him that it was not the quantity of rain that might fall in a given period, irrespective of other conditions, but the state of the land and drains when there was any unusual amount of rainfall. He himself had given expression to the same view in the following words:—"If a continuance of wet weather, having saturated the land and swollen the arteries and main drains, is succeeded by exceptionally heavy rain even of comparatively short duration, flooding will in all probability occur

[1] *Vide* River Nene, Thorney Lordship, and proposed dock, &c., at Wisbech. [Inst. C.E. Tracts. 8vo. vol. 252.]

Digitized by Google

in the lower portions of the district, seeing that the drains in their already gorged condition cannot carry away the extra quantity of water which may have fallen, with sufficient rapidity to keep pace with the accumulation. The periods of occurrence of rainfall, as well as the quantity which has fallen, must therefore exercise a considerable influence on the question of the production of floods. I take the summer of 1879, which was notoriously a wet season; but nevertheless no inconvenience was felt in a great part of the lower Nene district, because the rainfall was more uniformly distributed over the whole season, and not exceptionally heavy within a limited period, consequently the arteries were equal to the collection, and the main drains to the discharge, of the rain-water during the wet summer, and no flooding occurred." He entirely concurred in the principles laid down by Mr. Wheeler as those which were best adapted to prevent flooding, and to provide a remedy for the unfortunate state in which the Fen rivers were at present. The Author said that any improvements should commence at the outfall, and should be gradually carried upwards; that the channel should be widened, deepened, and in some cases even narrowed, as circumstances required, and that the channel should be made generally uniform throughout; by which he understood him to mean, in a word, that the river channel should be put into proper regimen. Reference had been made to the great multiplicity of authorities in these Fen districts. That was a great evil—an evil which prevailed to an extent which he believed few persons had any conception of. He had prepared a Table, when reporting on this subject to the Duke of Bedford, in connection with the River Nene; taking in round numbers the length of 30 miles from Peterborough to the sea, he found it was under the jurisdiction of fourteen different sets of Commissioners, namely, three over the channel, five over the north banks, and six over the south banks, of the river. The figures in the Table (see next page) gave the facts.

Sir John Coode

The river was thus overridden by bodies of Commissioners, notwithstanding that each was anxious to do its duty, as no one could be more interested in the matter than they were. With regard to the formation of Conservancy Boards, he thought that that was a matter rather outside the scope of the Paper. He was very anxious that the Institution of Civil Engineers should not be charged with arrogating to itself the duties which fell within the functions of the Imperial Parliament. He had nothing more to add, except to bear testimony to the great amount of industry and care with which the Paper had been prepared.

Digitized by Google

RIVER NENE.—Statement showing the number of Bodies having Jurisdiction over the River between Peterborough and the Sea.

NOTE.—In this statement no notice has been taken of the collateral but most important interests in connection with the Thorney Lordship and the Middle Level District.

District and Limits.		Length in Miles.	Description or Title of the controlling authority.	Nature of Works under control.
From	*To*			
Peterborough Bridge .	Bevis Hall	16½	Nene Navigation Commissioners—Third Division	Channel of river.
Bevis Hall	County boundary below Wisbech . .	4	Wisbech Corporation	,, ,,
County boundary . .	Crab Hole	10½	Commissioners of Nene outfall .	,, ,,
		31		
Peterborough . . .	Junction of Murrow Bank with River Bank at Guyhirne	13½	North Level Commissioners . .	Protection banks on north side of river.
Guyhirne	Wisbech Bridge (North Brink Bank).	5½	Wisbech Court of Sewers . . .	,, ,,
Wisbech Town . .	Frontage	1	Private owners	,, ,,
Wisbech Town . .	County boundary (Horse Shoe Bank) .	½	Wisbech Court of Sewers . . .	,, ,,
County boundary . .	Crab Hole	10½	Commissioners of Nene outfall .	,, ,,
		31		
Standground . . .	Guyhirne	12½	Commissioners of Nene Wash Lands	Powers to construct bank.
Guyhirne	Waldersea Sluice	3	Waldersea Commissioners . . .	Protection banks on south side of river.
Waldersea Sluice . .	Sluice just above Wisbech Bridge. .	2½	Wisbech Court of Sewers . . .	,, ,,
Sluice just above Wisbech Bridge . .	Wisbech Canal Sluice	½	Private owners	,, ,,
Canal Sluice . . .	County boundary (Eastfield Bank) .	1	Wisbech Court of Sewers . . .	,, ,,
County boundary . .	Crab Hole	10½	Commissioners of Nene outfall .	,, ,,
		30		

Digitized by Google

Mr. J. B. REDMAN wished to direct attention to the peculiar tidal condition in the river Nene referred to by Sir John Coode. He would ask whether, apart from any question of the lower portion of the river being throttled or not, it was not a phenomenon attached to any tidal river? The momentum of the tide in the upper reaches continued, and there was a current upwards long after the tide had ebbed at sea, which produced a simultaneous current downwards in the lower reaches. Precisely the same thing took place in the Thames, where the outlet was not encumbered in any way. At the moment of high water at Westminster the tide had ebbed two and a half hours, or one-third of the ebb at Sheerness, and the surface was in the Estuary 7 feet or 8 feet lower than in the port of London at the same moment of time. There must therefore be a current downwards in the lower reaches of the river, whilst there was a current upwards in the upper reaches. He also wished to bear his testimony to the great amount of labour bestowed by the Author upon the valuable statistics in reference to the four rivers, the united areas of the watershed of which were 5,709[1] square miles, or almost identical with the watershed of the Thames, which was 5,162 square miles. With regard to the earlier engineering in the Fen district, he thought it could hardly be conceived that a man like Sir Cornelius Vermuyden, the Dutch engineer, brought over during the Stuart period, could have overlooked the physical condition that the tidal oscillation in the Wash was something like quadruple that on his native shores; but he came to this country with inbred notions of excluding tidal waters by sluices. A century later his dogma was endorsed by Smeaton, whose reports were at the present day a text-book to the profession, but his recommendations in reference to Boston, and to Rye in Sussex, were no doubt mistakes. No reference had been made to a very large work carried out some thirty years ago within the Fen district. He happened to take the levels for the main drains from the sea to Peterborough. He well remembered at that period Vermuyden's old cut, Bevill's Leam and other streams leading up to Peterborough. There were windmills along each side of the main drains, which were also introduced by Vermuyden, the artificial ducts for drainage purposes being so much higher than the adjacent land that the water was lifted up by the windmills into these aqueducts, and in many cases the banks were so indifferent

Mr. Redman.

[1] *Vide* Salmon Fisheries Report—Map of Areas of Watersheds of Rivers, England and Wales.

Digitized by Google

Mr. Redman. that a large percentage of that water soaked back on to the land. The principle adopted in carrying out the work was to deepen the main drains, and, by the construction of a new main drain down to St. Germain's sluice, to get a much increased fall of outfall at the outlet, which was attainable from the fact that the cut constructed by the Rennies below King's Lynn, lowered the low water above King's Lynn to the extent of 3 feet. The effect of that work (the Middle Level Drainage) was to dispense with Vermuyden's mills, and, with a large number of steam-engines, to drain Whittlesea Mere, well known to sportsmen, 1 mile square, south of Peterborough, with the exception of a small portion below the level of the deepened drains raised by an Appold's pump. Undoubtedly there were three causes of the increase of floods in these rivers, one of which perhaps was not so obstructive at the present day, viz., navigation; next the antipathy landowners had to the introduction of salt water into the district; and thirdly, the divided jurisdiction, the upper districts desiring to deliver the water more quickly than the lower districts were inclined to receive it. No doubt in any public enquiry conducted in reference to this subject, the statistics with regard to these four rivers would be of great assistance and value. The region of the sources of these rivers was 350 feet above the sea, and was termed "flat," but the source of the Thames was only 376 feet above the sea. The oscillation of the tide in the Wash was very remarkable. Captain Parsons, R.N., of the "Porcupine," in 1871, informed him that the range of spring tides at Clayhole was 23 feet 4 inches, Lynn Road 23 feet 3 inches, Lynn 22 feet 5 inches; ten years previously the last was only 18 feet. The remarkable fact about the oscillation of the tides in the Wash was, that although the spring tides had such a great range (and they were 3 feet higher during the equinoxes), the neap tides were comparatively weak; in Clayhole 9 feet 2 inches, Lynn Roads 9 feet 1 inch, and at Lynn 9 feet 5 inches, showing that the indraught into the Wash had greater influence over the spring tides than over the neaps.

Mr. Bateman. Mr. J. F. BATEMAN, Past-President, said the magnitude of floods, and the best way of controlling them, were subjects which had occupied a great deal of his attention. The Fen rivers were rather peculiar, inasmuch as they debouched upon almost flat land with scarcely any fall at all. In that condition they were conveyed to the sea. He was surprised by one remark about these rivers made by Sir John Coode, whom he understood to say that while the water was absolutely falling at one point, it was rising at another; but that was the common state of almost all rivers

Digitized by Google

which had a tidal flow. In the Mersey, while the tide was still rising at Runcorn, 18 miles from Liverpool, at the latter place, the water had already fallen 6 feet or 7 feet in an ordinary tide. The momentum of all tidal rivers carried the water forward to such an extent that the higher the reach within the range of the tide, the higher the water rose, and in many cases, for considerable periods after the water had fallen at sea or the immediate neighbourhood of the sea. He knew very little of the rivers on the east coast of England; but he did know something of the river Irwell, for he had frequently had occasion to report on that river. Every river must be considered with reference to its own peculiar position, its distance from the hills, the fall of its bed, and the geological formation through which it flowed, as well as the quantity of rainfall from which the floods arose. All these things had to be taken into consideration; and the circumstances of rivers on the east coast were so entirely different from those in mountainous districts—as in Scotland or Wales, or the West Coast of England—that no uniform mode of dealing with rivers generally could be laid down. Besides this, the conditions of riparian owners—those who lived on the high lands, and those on the low lands—were so various and antagonistic one to the other, that it would be exceedingly difficult to bring any river basin into such a condition that all parties would agree to the adoption of a particular system by which the floods might be reduced. Mr. Bateman.

The following observations on floods in various rivers in the North of England and in Scotland might be interesting to the members. Such observations were of great value to the hydraulic engineer and to all who had to provide for the safe passage of water:—

In the year 1833 a flood in the river Medlock did much damage in the lower parts of Manchester. The drainage ground to the river was 12,000 acres. The flood at its maximum height amounted to 2,000 cubic feet per second, equal to a depth of 4 inches of rain flowing off the ground in twenty-four hours. This flood was equal to 16⅔ cubic feet per second from each 100 acres of collecting ground.

In 1856 a flood in this river did much mischief in the vicinity of Oxford Road in Manchester. This flood measured at its maximum 2,400 cubic feet per second, equal to 20 cubic feet per second from each 100 acres. In 1857, during a flood, the river Medlock discharged 3,060 cubic feet of water per second, or 25½ cubic feet per second from each 100 acres.

In February, 1852, the mean flood of the river Etherow, in Longdendale, at the Manchester Waterworks, from 15,400 acres,

Digitized by Google

Mr. Bateman. was, during twenty-four hours, at the rate of 10 cubic feet per second from each 100 acres, equal to a depth of $2\frac{4}{10}$ inches of water coming off the ground in twenty-four hours. When at its highest the volume of the discharge was from 3,600 to 4,000 cubic feet per second, or 25 cubic feet per second from each 100 acres. It was during this flood that the Bilberry reservoir, near Holmfirth, was destroyed.

In August, 1856, from a drainage ground of 7,000 acres at the Manchester Waterworks, the mean flow of the streams for seven hours and forty minutes was 2,100 cubic feet per second, being equal to 30 cubic feet per second from each 100 acres, and to $2\frac{1}{2}$ inches depth of water flowing off the ground in that time, or to 7 inches in twenty-four hours. On this occasion the river Irwell, in Manchester, was flooded, and much damage done to low-lying property.

On the 7th of May, 1862, from 5 P.M. to 7.30 P.M. the mean flow of the streams at the Manchester Waterworks, from 7,000 acres, was 2,626 cubic feet per second, being equal to $37\frac{1}{2}$ cubic feet per second from each 100 acres, and 0·93 inch of water over the whole surface, or at the rate of 9 inches in twenty-four hours. The average flow of the same flood, from the same ground, for seven hours, was equal to 24·7 cubic feet per second from each 100 acres, and for thirteen hours it was $15\frac{1}{2}$ cubic feet per second per 100 acres.

In November, 1866, serious injury was done to the low-lying parts of Salford and Manchester, as mentioned in the Paper by Mr. Jacob. At Agecroft bridge, above Salford, in the river Irwell, from a drainage area of 132,000 acres, the flood discharge measured $18\frac{1}{2}$ cubic feet per second from each 100 acres, or a total of 24,500 cubic feet per second. In Manchester the volume was 18·8 cubic feet per second per 100 acres after its confluence with the river Irk, the latter river contributing to the flood at the rate of 20·4 cubic feet per second per 100 acres. On this occasion, at the Manchester Waterworks, the average amount of water flowing from 14,335 acres was for twelve hours together 3,347 cubic feet per second, being equal to a depth of $2\frac{3}{4}$ inches of water flowing off the ground in that time, and to an average flow of 23·4 cubic feet per second from each 100 acres. The maximum discharge of this flood at the Bilberry reservoir, near Holmfirth, the drainage ground to which adjoined that of the Manchester Waterworks, reached 38 cubic feet per second from each 100 acres. The preceding season had been very wet, the ground was thoroughly saturated, and the springs and streams were all swollen.

Digitized by Google

Mr. Bateman.

From the beginning of June to the 19th of November, the rainfall at the Manchester Waterworks amounted to 36 inches. During the three days of the flood, viz., the 16th, 17th, and 18th of November, the rain gauges showed a fall of 4⅓ inches. In the flood of August 1856, already referred to, the rainfall in Longdendale amounted to 3·96 inches in three days, but it followed a comparatively dry period, and occurred at a season when the absorption by the ground would be considerable. In the flood of February, 1852, the depth of rain was 4·6 inches in five days, being a little more than that which fell in three days in November, 1866.

In October, 1854, at the Glasgow Corporation Waterworks, the volume of water discharged from Loch Lubnaig, from 44,600 acres, averaged 5,500 cubic feet per second during twenty-four hours, being equal to 3 inches in depth of rain flowing off the ground, and to 12⅓ cubic feet per second from each 100 acres. At Loch Katrine, on the same occasion, the quantity of water stored and discharged in two days was equal to 6 inches depth of water flowing off the ground in that time.

In the river Clyde, at Carstairs, the drainage ground being 190,000 acres, the floods in the winter of 1856 and 1857 averaged 20,000 cubic feet per second, equal to a depth of 2½ inches of water flowing off the ground in twenty-four hours, or to 10 cubic feet per second from every 100 acres, besides all the impounded water in the long and gently sloping valley of the Clyde, which was greatly flooded.

A flood in December, 1879, at the Manchester Waterworks, amounted to 2½ inches of water flowing off the ground in nineteen hours, and to 2¾ inches in twenty-three hours, from 14,335 acres; when at its maximum it flowed at the rate of 32⅓ cubic feet per second per 100 acres for two hours and twenty minutes. In March, 1880, another flood at the Manchester Waterworks averaged for one hour nearly 27 cubic feet per second both at Woodhead and Torside, the latter having a drainage of 14,335 acres; for twelve hours it averaged 16⅓, and for four hours 24¼, cubic feet per second per 100 acres. This flood, as well as the preceding one, was no doubt moderated by the large reservoirs in which it was measured.

Sir John Coode.

Sir JOHN COODE said, in explanation of what had fallen from Mr. Bateman, he did not intend by any means to convey that the example to which he referred was unique. All he wished to call attention to was that it was a very remarkable case, that in so short a distance comparatively, there should be so great a dif-

Digitized by Google

Sir John Coode. ference in level. He was well aware that a similar state of things prevailed in rivers in every part of the world, but he merely mentioned this as a notable example.

Mr. Barry. Mr. J. W. BARRY ventured to advert to the circumstances of the river Hull, which discharged its waters into the Humber. Those circumstances entirely confirmed the views put forward by Mr. Wheeler. The river Hull, like the Nene, the Welland, and the Ouse, drained a long, flat valley, with low embanked land on each side, lying at a considerable distance below high-water mark. This flatness of the land was so remarkable that, at a distance of 20 miles from the mouth of the Hull, the level of the ground was no more than from 6 feet to 6½ feet above low water of neap tides in the Humber, and was much below low water of neap and spring tides in the Hull itself. The want of system in this case, and of authority to deal with the problems of the drainage of the district, were undoubtedly most pernicious to the whole country. On the river Hull there were no less than five drainage districts, a Navigation Commission, a Court of Sewers, and a Corporation, all claiming jurisdiction in some way over the river. The result of the conflict of authority was that nothing was ever done to the river; it was never cleaned out; it was never regulated; weeds were allowed to grow, and people were allowed to put obstructions in it. At a distance of only 2½ miles from the mouth of the river in the Humber, the low-water line of spring tides was 15 feet higher than in the Humber itself, and at a distance of 1 mile from the mouth it was 9 feet higher than in the Humber, and nothing was done to improve the river. The result of this unnecessary height of the low-water line was that land which might be adequately drained at a distance of 20 or 25 miles from the mouth was more or less waterlogged, floods occurred every year, immense damage was done, and thousands of acres of agricultural land were depreciated in value. All this pointed unmistakably to the desirability that legislative action should take place to put the whole of the river and banks, and the streams flowing into it, under some central authority, who would be able to deal with the different conditions which affected the benefit of all. It had been said that this was not an engineer's question. Perhaps it was not altogether so; still there could be no doubt that engineers had frequently to deal with these difficult questions of co-ordinate authorities; and if the Government took up this matter, they would probably look to engineers for advice as to the mode of so constituting Boards of Authority that they should be so able to deal with all

Digitized by Google

the points at issue. Perhaps it was as well to point out that this system of centralised authority over rivers was no new thing. In the days of Queen Elizabeth the Court of Sewers was instituted on almost all rivers, and was supposed to be the authority which would represent public and local interests in all questions affecting each river. Unfortunately the Court of Sewers in Yorkshire had become to a great extent obsolete. They had no adequate rating powers, and no official machinery such as was necessary for raising money or doing the works which were required from time to time; but he thought that such a representative body as the Court of Sewers was meant to be, was a nucleus for legislation in the future. Before sitting down, he would allude to one point which on the Hull was an instance of what was taking place on many other rivers. In its passage through the town of Hull the river had been permitted to be encroached upon by wharves, warehouses, berthing places, and various obstructions, and the effect had been to prevent any radical improvement of the river above the town. It had been suggested by numerous engineers, for a length of time extending over many years, that the proper remedy for this state of things was an avoiding cut which would take the river to the Humber without the necessity of its passing through the town; but, as at Wisbech and other places, the conflict of interests had been so great that it had been found impossible to get anything done. He thought that anybody who had had experience of a similar state of things would do well to put it on record, because it would form an important contribution to the elucidation of this difficult subject, and might be referred to with advantage in the legislation which he believed was imminent. Mr. Barry.

Mr. J. Clarke Hawkshaw.

Mr. J. CLARKE HAWKSHAW observed, that, in the spring of 1877, he spent some weeks in examining the district of the Witham. In that district in the winter of 1876–7 a tract of land, 40,000 acres in extent, was flooded. At the time of his visit a great part of the Fen land was still under water, and the flood-marks were visible along the banks of the Witham and its tributaries, so that he was able to trace and map them. Sir John Coode had quoted the Nene as an example of a river under divided jurisdiction, and he thought the Witham might be well compared with it in that respect. In a Paper on "River Control and Management" which he had read before the Mechanical Section of the British Association in Dublin,[1] he had named seventeen separate authorities having jurisdiction over the Witham and its banks

[1] *Vide* Report of the forty-eighth meeting, 1878, p. 687.

Digitized by Google

Mr. J. Clarke Hawkshaw.

and main tributaries, without including the Drainage Commissions in the Fen land below, which, if added would make up forty different bodies having jurisdiction over the Witham and the various waterways connected with it. There was one district adjoining the Witham which well showed the difficulties arising from such divided jurisdiction. Above Lincoln there was a flat tract of land stretching towards the Trent. Part of it was at such a level that it must always be drained by pumping. The Fosdyke passed along this tract between Lincoln and the Trent. It was a navigation, but it received the waters of the River Till, which drained an area 52,000 acres in extent, and it was therefore something more than a navigation. The waters of the Till flowed through Lincoln. They could flow, as far as levels were concerned, to the Trent, but were not allowed to do so, and found their way down to the sea by Boston. At Torksey, where the Fosdyke entered the Trent, there were banks to protect the low land from the flood-waters of the Trent. A short time before he was there the Trent rose between 4 feet and 5 feet above the flood-level of the Fosdyke. It was almost by accident that the bank at Torksey was prevented from bursting. He did not know what body had proper jurisdiction over the banks; certainly those who were interested in preventing its breaking had none; and it was saved, he was told, mainly by the exertions of the Lincoln people. If the bank had burst the land would have been flooded between the Trent and Lincoln by a river of a totally different drainage district. Such a flood occurred in 1852. An area about 30 square miles in extent, was flooded by the bursting of the Trent bank, and part of the waters of the Trent found their way through Lincoln down to the sea at Boston. That showed the difficulties of divided jurisdiction. The district flooded had no control over the bank which failed, and even Lincoln itself and the tract between it and the sea was liable to be flooded. If the country were divided into drainage districts, an arbitrary line of division would have to be drawn between the Trent drainage district and the Witham drainage district, and a bank, to be under the control of the districts liable to be flooded, would have to be made between the Trent and Witham area. During the floods of 1876 a large part of Lincoln was flooded by the Witham. It appeared to him that under the proposed River Conservancy Bills the town population would escape a taxation, to which, he thought, they should be liable with all others who would be benefited by the conservancy of rivers. The towns were directly interested in rivers in many ways. They were interested

Digitized by Google

in them for the purposes of recreation and for water supply (London drew a great part of its water supply from the Thames), and often for purposes of navigation. Towns were often the greatest offenders with regard to rivers, both in polluting them and in obstructing the waterways. That was well exemplified in Lincoln, where the waterway through the city was very confined. In his father's report on the district[1] he recommended a new cut, which would take the Witham waters clear of the city of Lincoln, and he believed the same method had been proposed in the case of Wisbech, where the town formed a similar obstruction. By the fall of rivers through towns the way in which the rivers were obstructed could generally be seen. At Wisbech there was a fall of 3 feet per mile through the town, whereas the fall from Peterborough to the sea was only about 5½ inches per mile. The same thing was observable at Norwich. He went there in 1878, shortly after a large part of the city had been flooded, and took the flood-levels through the city. The flood occurred at the upper part, where there was a mill, and the levels there well illustrated what an obstruction the city was. At the mill there was a fall of 3 feet; between the mill and the foundry bridge below the city there was a fall of 3 feet 7 inches in little more than a mile; and from the foundry bridge to low-water level at the sea, a distance of 29 miles, there was a fall of only 2 inches per mile when the river was in its normal state, and in time of flood of only 3½ inches, showing what room there was for improvement through the city. The same thing might be said with regard to Oxford, where, though the city itself was not flooded, a large part of the district above was flooded in a great measure by the obstructions caused in the city. Any improvement of the river near the city would be very costly as compared with other portions of the river, mainly owing to the obstructions caused in the city itself. There were many other instances in which towns were flooded in the same way by obstructions which they themselves caused. At Burton there had been two floods in one year. The Trent took a short cut through the town, and flowed down one of the main streets, which was flooded 3 feet deep, and the current was so strong that it was found difficult to navigate the streets in boats. These cases showed, he thought, why towns should be taxed in some measure for improvements in rivers in which they were so much interested. In the River Conservancy and Floods Bill, it was pro-

Mr. J. Clarke Hawkshaw.

[1] *Vide* Mr. (now Sir John) Hawkshaw's Reports to the Witham Drainage Commissioners, 1861 and 1862. [Inst. C.E. Tracts, 8vo., vol. 325.]

Digitized by Google

Mr. J. Clarke Hawkshaw.

posed that an urban sanitary authority might, on application, be constituted a Conservancy Board, or that a Conservancy Board might contract with an urban sanitary authority for the execution or maintenance of works. That, of course, was a step in the right direction; but he thought that towns ought to be rated as well as adjoining lands for the conservancy of rivers. In the Bill of 1881 there were some marked improvements on the old Bill of 1877 with regard to the division of districts into different descriptions of land. In the Bill of 1879 three divisions were named, flood-lands, intermediate lands, and uplands. At the Conference on national water supply at the Society of Arts in 1879, he stated that in his opinion it was a mistake in that Bill to attempt to define the lands as it did. The flood-lands were defined as lands liable to flooding. In the Bill recently before Parliament they were called low lands and were not defined. He thought that low lands should include lands lying below the flood-level. It was an easy matter in most rivers to lay down a line along the banks, which could be regarded as a flood-line; such a line could be laid down once for all, so that the landowners would know within what district their land lay. In the Bill of 1879 intermediate lands were defined as lands drained by subsoil drainage, but in the Bill of 1881 they were called midlands and were not defined. He thought it was very questionable whether it was advisable to have midlands at all. In the old Bill it was evidently intended that they should not lie within any definite or compact area, but should be lands taken about here and there, and especially land drained by subsoil drainage. The only midlands which it would be advisable to have, if there were any, would be lands laying a short distance above the flood-lands. Another line might be laid down 2 or 3 feet above the flood-lands, between which line and the flood-line the midlands should lie. There was no doubt that the lands adjoining flood-lands, though not themselves liable, or only occasionally, to floods, might be much benefited by the adjoining lands being freed from floods. Pieces of land were often isolated by floods, and such lands would be at once benefited by the removal of floods, though they were not themselves flooded. On the Upper Thames, along 40 miles of the river, a flood-line had been laid down, and all lands within it were flood-lands. Another line had been laid 5 feet higher on the survey, and all within that would be regarded as midlands. So also on the Upper Witham, which was under the jurisdiction of the Lincoln Sewers Board, a flood-line had been laid down, and also a line 2 feet above it, and the two descriptions of area so enclosed

Digitized by Google

were rated at different rates. The principle on which he thought taxation should be made was that all lands lying within the drainage area ought to pay in the first instance, not on the ground that they were benefited, but from the fact that they drained into the rivers. All the water found its way to some river, or in some way affected the water which found its way into some river, and the lands ought therefore to be taxed on that ground alone, for the purpose of maintaining the river in a condition to pass the drainage of the country to the sea without injury to any one. That principle had been recognised in Holland. Though it was sometimes said that the lands in Holland were very different from those in England, being mostly low lands, that was not altogether the case, for there were large tracts never liable to floods. No doubt their ideas of high lands were different from English ideas. In Rheinland, for instance, there was an area of 260,000 acres in which land was called "high" land, which was 10 inches below the mean level of the sea. The subject on which he had been touching might perhaps be considered beyond the limits of engineering; but he thought that engineers, who had experienced the impossibility of dealing rightly in the present state of things with drainage questions, ought to be able to assist in overcoming the difficulties which arose from having no proper system of river conservancy. Mr. J. Clarke Hawkshaw.

Mr. R. B. GRANTHAM observed that he had had considerable experience in many drainage districts, especially those referred to in Mr. Wheeler's Paper, in some of which he had been officially engaged. Between 1862 and 1880 he had held inquiries into thirty-five applications under the "Land Drainage Act, 1861" in sixteen counties, for the formation of Drainage District Boards and Commissioners of Sewers, all of which were authorised, and had been of advantage in draining lands and increasing their value where they had been carried out. The numbers were: Norfolk 9, Somerset 8, Gloucester 3, Oxford 3, Lincoln 3, Hereford 2, Cheshire 2, Durham 1, Worcester 1, Brecon 1, Northampton 1, Nottingham 1, Merioneth 1, Devonshire 1, Lancashire 1, Cambridge 1. The largest area involved was 55,452 acres, relating to the Thames valley, Oxford, in 1875; and 11,259 acres in connection with Kings Sedgmoor Somerset, in 1864. The total area was 143,754 acres. He had been principally engaged in connection with the Land Drainage Act for arranging the country in districts for the improvement of river drainage; but perhaps new legislation would entirely do away with them or embrace them under a single jurisdiction; the latter would, he thought, be the most Mr. Grantham.

Digitized by Google

Mr. Grantham. equitable method to adopt, for in many of the districts large sums of money had been spent in carrying out the Act. One of the largest areas on which he had had to report was that of the Somersetshire drainage. He was required to examine into the state of the floods, their causes, the effects on the health of the inhabitants, and the mode of preventing them. After these districts were formed, the largest of them was selected and an Act of Parliament was passed upon the same principle as the Thames Valley Drainage Act. The Act was not yet in operation, but the districts had been laid out. His opinion with regard to the conservancy of rivers was that each watershed should be formed into a drainage district. Very large ones might be divided, but small ones thrown together so as to make it worth while to form a large body of commissioners to manage each district. Those districts should then be divided under smaller boards on a similar plan to that of the Land Drainage Act of 1861. He was examined before the Lords' Committee in 1877, and the Report of that Committee was, he thought, the most valuable document in existence with regard to the rivers of the country. He quite agreed that it was of no use to form reservoirs for the reduction of floods. If any storage was necessary it was for the purpose of supplying country places with water for irrigation and power. Mr. Grantham had also reported for the Corporation of Bedford, upon the state of the river Ouse, about the time that Mr. Abernethy was examining the lower part of the river, and he found the navigation in a very bad state. The locks just kept the water up, and no more, and great injury was often done to the country. There were no funds for improving the navigations or keeping them in ordinary repair in consequence of their having been, in most cases, superseded by the railways. One occasional cause of flood (as he had found in Somersetshire) was the navigation being left to itself, so that the river had silted up. The bottom of the river Ouse had silted up to a great extent aided by the growth of weeds, and the sectional area for the reception of floods was consequently much diminished. Another reason for the flooding was that there was constant pumping from the Fen lands; then Denver sluice kept up the water and flooded all the country to St. Ives and Huntingdon, so that the floods actually now went over the ancient banks that were formerly a protection to the country, but in so doing relieved the country of excessive floods to a great extent.

Mr. Marten. Mr. H. J. MARTEN thought that the title of the "Rivers Conservancy and Floods Prevention Bill," as introduced in the last Session of Parliament, was a misnomer, so far as the latter clause

Digitized by Google

of it was concerned. He did not imagine any engineer would suppose that powers to be given or exercised under that or any other Act of Parliament would prevent floods. A Bill, however, the title of which stated that to be one of its proposals, would be very likely to mislead the general public. So long as there were excessive rains and rapid thaws following upon deep snows, floods would follow, and he doubted whether, even if they could be entirely prevented, it would be an advantage to the country at large, or even to the lands themselves that were now occasionally flooded. Setting aside all other contingencies involved in connection with the subject of the prevention of floods, there were many cases in which floods "quickly on and quickly off" certain lands, were acknowledged to be a positive advantage. Mr. Marten.

The objects of the "Rivers Conservancy and Floods Prevention Bill," as stated in the 8th Clause, were, 1st, "the Conservancy of Rivers," and, 2nd, not "the prevention of floods," but, "the protection of land from injury by floods." This was an object not only widely different from "the prevention of floods," but was both a reasonable and practical one, and was worthy of careful consideration, with a view to its attainment. There could be little doubt that by carrying into effect the provisions of an Act of Parliament based—not altogether—though to a considerable extent on the principles laid down in the Bill referred to, extensive and valuable areas of land, now not unfrequently greatly injured, and in some cases absolutely ruined by floods, might to a large extent be protected from injury.

It was a singular circumstance that whilst the "Conservancy of Rivers" was mentioned in the Title, and described in the Bill as one of its principal objects, no definition of the term "Conservancy of Rivers" was given in it. The 55th clause of the Bill contained a definition of the terms "Conservancy Board," "Conservancy District," and "Conservancy Authority," but no information was afforded as to what was to be understood as included within the term "Conservancy of Rivers." He thought this term ought also to be defined in the Bill, as hereafter, no doubt, a great many important points would turn upon the question of its exact legal meaning. Mr. Jacob had, in his opinion, very fairly defined what he believed was generally understood by the term "Conservancy of Rivers," namely—"first, the preservation of a stream for domestic, sanitary, and industrial purposes by preventing pollution and interference of other kinds; secondly, its maintenance and regulation for navigation; thirdly, for the culture and preservation of fish; and finally, for the effectual drainage of the district through which the

Digitized by Google

Mr. Marten. stream pursues its course, including abatement of floods; or, rather, as he should be inclined to put it, "the abatement of injury to lands by floods." He did not quite concur with the order in which Mr. Jacob had named the various matters to be included within the term "Conservancy of Rivers," but nevertheless the objects to be aimed at and included in the term were fully set out, and he considered they should be as fully set out in any Act of Parliament professing to deal with the question of rivers conservancy, as otherwise, in the case of local and other inquiries, there would be a great danger of important interests being excluded from consideration, in consequence of questions that might be raised as to whether they were or were not included in the term "Conservancy of Rivers."

By the 3rd and following clauses in Part I. of the Bill any sanitary or conservancy authority having jurisdiction within any part of a river basin may apply for and might have that portion of the river basin over which such authority might exercise jurisdiction constituted a "Conservancy District." Taking the case of a river like the Severn, with which he was more intimately concerned, it was not improbable that a large proportion of the numerous sanitary authorities having jurisdiction within its drainage area of 6,000 square miles, would apply to have the districts within which they exercised jurisdiction constituted "Conservancy Districts." If (in the absence of other provisions to which he would hereafter refer) such applications were granted, a state of things would arise similar to that which had been described as so injurious on the Witham and Fen districts—namely, a multiplicity of conservancy authorities and districts would be created, each having jurisdiction over a part only of the river basin, each more or less jealous of its neighbour, without cohesion, and without knowledge of, or consideration for, the general interests of the river basin considered as a whole. In order to prevent such a state of things he thought that the drainage area of every river, from the sources of its remotest tributaries to its outlet in the sea should have one body constituted within it, to be called, say "The General Conservancy Board" of such river basin, which should be charged with special duties with respect to the whole of such drainage area, and should stand in a special relation to every other District "Conservancy Board" formed within it. The duties of such "General Conservancy Board" should be to cause accurate plans and sections to be prepared of all river-beds and water-channels, of all areas liable to be flooded, and of all weirs, dams, embankments, and other works within the water-shed which might in any way affect the discharge

Digitized by Google

of the main river or its tributaries; to collect information with regard to the incidence of rainfall, the periods, volumes, and effects of floods; to issue telegraphic warnings with respect to apprehended floods; to receive notice of any new work or alteration of any existing work intended to be executed upon any stream, or within any area liable to be flooded within the water-shed, with the right as the authorised representative of the general interests of the whole river basin; to attend and be heard at any local or public inquiry with respect to such intended work, and, in the event of its disapproval of any work proposed to be executed without public inquiry, to have the right of claiming one in the public interest. The General Conservancy Board should also have the right to initiate proceedings under the Rivers Pollution Act in those portions of the water-shed outside the jurisdiction of any District Board, and, subject to appeal, of directing proceedings to be taken by any District Board. It should also initiate and have the control of all main outlet and other important works which might be deemed so far for the common benefit, as to be carried out by means of funds to be raised from the whole drainage area, and it should have the right to move the Local Government Board, or other public authority interested, to hold a public inquiry, with a view to direct any District Conservancy Board to execute work for the improvement of the river within the limits of its jurisdiction, and other like matters. With some such additions and alterations, which could easily be made in the Bill, he considered that a good working measure might be framed, but he doubted whether the Bill, as it at present stood, would prove effectual. The promoters ought not to expect too much, nor ought they to lead their friends to anticipate that a great deal could be accomplished under any "Rivers Conservancy Act" in a short time. Nothing should be done in haste; ample time should be allowed for the collection of the requisite facts, for maturing the necessary plans, and for their full consideration and discussion by all interests affected. River improvement works, even when most economically designed, were necessarily expensive, and it was due to the landowners and others who would have to contribute the funds that every effort should be made consistent with efficiency, to keep the expenditure as low as possible.

Mr. Marten.

Having said this much with respect to the important subject of rivers conservancy in its parliamentary aspect, he would only remark in conclusion that he considered that much useful information had been laid before the Institution in the Papers under discussion. In his paper on the Irwell, Mr. Jacob had given an

Digitized by Google

Mr. Marten. account of a flood in November 1866, with respect to which it was stated that, just above the junction with the Irk, a volume of 24,000 cubic feet of water per second was discharged on that occasion during the height of the flood from a drainage area of 135,500 acres. This discharge represented a daily flow off the drainage area in question at the rate of 4·20 inches of rainfall. This of itself was a most unusual rate of discharge from a drainage area of this extent and description, and was remarkable as exceeding the amount of rainfall over the area on the day of the flood at the places mentioned in the Paper. It was, however, quite possible that the unrecorded rainfalls in the upland portions of the drainage area might have been so much larger than those named, as fully to justify the estimate of the discharge on the occasion in question.

Mr. Eachus. Mr. G. E. EACHUS thought that, without looking too closely to the title of the Bill, its main object was to prevent injuries from floods by one of two or three courses, improving the channels of the rivers themselves, by storage reservoirs, or by the interception of the rainfall which made its way too rapidly into the water-courses. The section of the river Irwell (to take an extreme case) represented the bad effect produced in most rivers that had a rapid fall of rain from the high lands into a flat channel, and the difficulty was to get rid of the effect of the excessive rains falling into the channel in that way. One method had not been touched upon, that of providing high-level intercepting channels, having a sort of contour fall, into which the excess of storm waters might be conveyed, and so taken down to a lower section of the river, where few or no works would require to be executed. The effect of the tunnel proposed for the relief of Salford would be to convey one-third of the water, or about 9,000 cubic feet of water, per second, from E to D in forty minutes, and the result would seem to be that to the extent of about 150,000,000 gallons of water, the land would be relieved from flooding. The same relief might be given in the way which had been suggested (he did not say it would be a better way) by a storage reservoir capable of holding that quantity of water. As soon as the forty minutes had elapsed, unless the lower portion of the river had a sufficiently large sectional area (which it did not seem to have, as the land was flooded on both sides), to take the whole quantity of water coming down, there would be no further relief to the floods. Channels, cut at higher levels, would intercept a considerable portion of the storm waters in times of flood and convey them down below the land liable to be flooded, or, if there was no such point, as low down the river as it was possible, only the outfall of the river would

Digitized by Google

then require to be banked or deepened and otherwise protected from floods. The cost of constructing high-level intercepting channels would also seem to indicate what contribution ought to be made by the high lands towards the prevention of floods. The chief objection to storage reservoirs existed only in flat districts where it was practically impossible to make them of such depth as to require reasonably small areas of land, and, even if this could be effected, reservoirs so situated were not easily voided when required. Mr. Eachus.

Mr. THOMAS COOTE had some difficulty in understanding the mode in which tidal waters affected floods. In the case of the Ouse, just in proportion as the outfall was enlarged and the tidal waters were admitted up the rivers (which all engineers seemed to think a considerable advantage), they appeared to back up the floods and prevent them from reaching the sea. The problem he should like to hear solved would be this: given such an improvement of the river that the tidal waters were admitted to an extent calculated to raise the waters upwards, say 1 foot, in proportion to 2 feet improvement of the outfall, what effect would that have upon the discharge of floods into the sea? He had seen the effects already produced, and did not quite understand how the difficulty was to be overcome. With regard to the introduction in the Conservancy Bill, of the question of storage of waters, he thought it would be an exceedingly bad thing; but a permissive clause in the Bill with reference to villages or towns that might choose to take advantage of the permission might, perhaps, be usefully introduced. Mr. Coote.

Mr. A. GILES observed that the seventeen Boards of Control in a small district about Lincoln, and the effect of that divided authority, showed that the old saying, "In the multitude of counsellors there is wisdom," did not always apply. Mr. Wheeler had well described the difficulties of the Fen rivers; but there were other valleys subject to similar misfortunes. He alluded to those afflicted by navigations, mill-streams, water-meadows, and drainage. The valley of the Wey was a notable instance, and the want of efficient drainage in such valleys was often complicated by the smallness of the bridges through which the floods had to pass. In Austria there was a *Begehungs Commission;* and no one could put a bridge across a river without having its dimensions submitted to the Government authorities, who generally insisted upon a sufficient width for the passage of extreme floods. If that system were adopted in England it would be impossible for such a case to happen as that described in Mr. Wheeler's Mr. Giles.

Digitized by Google

Mr. Giles. Paper, where "the bridges over the Hundred-Foot river have only half the area of the waterway of those at St. Ives 12 or 14 miles higher up." That was a pretty good proof that legislation was wanted upon the subject. He was no advocate for that sort of paternal legislation which assumed that a man was incapable of taking care of himself or his property; but he thought that in the control of rivers not only was legislation wanted, but very efficient legislation. There was legislation to prevent a dirty fellow committing a nuisance or accumulating filth and rubbish in front of his neighbour's premises to the detriment of his health and comfort; and there was no reason why a landowner or a mill-owner should not be under the control of some central authority to prevent his works up-stream from becoming a nuisance to his neighbours down-stream. A few years ago he was concerned in some drainage works in Somersetshire, where considerable difficulty was experienced in levying rates upon the various lands and levels for the purpose of providing new sluices and efficient drainage. The matter had culminated in an Act called the Bridgwater Act, for the purpose of regulating the drainage of the watershed of the Parret near Bridgwater; and unless legislation upon the subject comprised the drainage of the whole of the various watersheds it would never be efficient. He did not think any general rules could be laid down for the drainage of rivers varying so much in their circumstances as English rivers did; but there could be no doubt that, with more efficient drainage of agricultural lands, the outlets formerly sufficient were now quite insufficient, and he believed that in widening those outlets it would be found desirable to make the bottoms of the channels narrow and the slopes much flatter than they were at present.

Mr. Shelford. Mr. SHELFORD had not come prepared to speak on the subject of river conservancy, but he should not like Mr. Coote to go away without an answer to the question which he had put to the profession. That gentleman appeared to be under the impression that the admission of more tidal water up a river diminished its capacity of discharge. That was an entire mistake. A tidal river discharged fresh water, not by a direct stream but by pulsations, to the sea; and each pulsation consisted of a large quantity of tidal water, which tidal water, if there was a fresh in the river, consisted of fresh water, and only consisted of salt water when there was an insufficient quantity of fresh water to supply the volume, consequently the larger the tidal capacity the greater the pulsations by which the fresh water was discharged, and the greater the quantity which entered the sea. With regard to the first Paper,

Digitized by Google

Mr. Shelford.

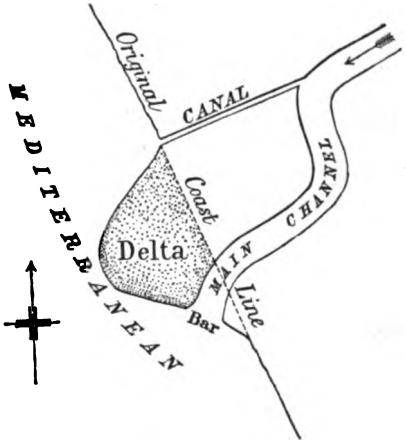
having been three or four years in charge of the river Nene as resident engineer under Mr. John Fowler, Past-President Inst. C.E., he had a considerable acquaintance with the district, an acquaintance which he had had occasion to keep up from time to time, and he could quite corroborate Mr. Wheeler's statements, and add his testimony as to the soundness of the information which the Paper contained and the principles which it advocated. He could not admit, however, that the conflict between the ebb current and the flood invariably had a tendency to throw up a bar at the point where the confined channel debouched into the open. The question of bars affected the whole question of river improvement, and therefore of river conservancy. He did not hesitate to say that there was no such conflict as that referred to by Mr. Wheeler. The bars in all the rivers with which he was acquainted were formed, not by any such conflict, but by the cross action of the sea drifting the sand and the shingle across the mouth of the river, the velocity of the current of which was insufficient to remove it. Some years ago he had contributed a Paper "On the Outfall of the River Humber,"[1] in which he had set out somewhat fully the causes in operation at the outfall of that large river, and there was precisely that action which he had described. The sea was endeavouring to close the mouth of the estuary as in many other cases. He would, however, prefer to take the case of a tideless river, because it was free from the complications of the tide, and one which had a bar—the Tiber, for instance. The natural line of the coast where the Tiber fell into the Mediterranean was south-east, through which the main channel discharged at right angles. This channel had nothing to do but to discharge fresh water. There was no tide, and during the greater part of the year it was almost dry. The river brought down a large quantity of detritus, which it discharged at the mouth and spread out in all directions. The prevailing winds from the south drove the detritus northwards across the mouth, creating a bar and forming a delta to the north. With a view to effect an entrance into the river, which was deeper inside the bar, and to relieve the floods, one of the Roman emperors had excavated a canal about 100 feet wide across the country from the main river to the sea northward of the delta, and that was the other mouth of the Tiber and the only navigable one at the present day. The emperor might have been astute enough to foresee the result; at all events, what happened was this: the mouth being upon the leeward side of the delta, the delta itself protected the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 472.

Digitized by Google

Mr. Shelford. new outfall of the river; in fact, the action which closed the main channel preserved the artificial one. What would happen if the Mediterranean were a tidal sea and the Tiber consequently a tidal river? The same thing, except that there would be in addition a large quantity of tidal water flowing into the mouth of the main channel and out, the effect of which would be to increase the scour and depth of water, especially within the river, leaving a bar of sand just outside the mouth, deposited by the action of the sea, and not removed by the tidal current except where it was of sufficient velocity. He had alluded to the Tiber also because it had received more attention for some years past than almost any other river, with a view to its scientific improvement for the pur-

FIG. 1.



Mouths of River Tiber.

pose of preventing floods in Rome. He had read the discussions upon some thirty projects that had been brought forward for that purpose, most of which might be referred to one of two principles —the old principle of embanking floods from the lands; and the modern principle of lowering the bed and consequently the water line. It so happened that the question had been decided on a side issue, namely, the ornamentation of Rome. The engineers who advocated the lowering of the bed must necessarily have spent a large sum of money upon the outfall and upon the river below Rome without anything to show for it, while those who advocated embankment by handsome walls, like the Thames Embankment, with parapets and drives, provided something to look at as well as something to keep out the floods, and they were naturally

Digitized by Google

favoured, because they had something to show for their money. Mr. Jacob in his Paper on the Irwell had stated that the embankment of a river was the least expensive way of increasing the hydraulic mean depth, and therefore the capacity for discharge, and he entirely agreed with him; but it was that very thing which had prevented river improvement generally in the country, because it had enabled one district to free itself at the expense of another. In the discussion of a Paper upon River Conservancy, he thought that some one, at all events, should insist upon the importance of the modern principle laid down and acted upon by such men as Walker, Rennie and Stephenson so successfully in the Fens—the principle of lowering the low-water level. Mr. Shelford.

Mr. G. J. Symons had been recently told that two or three hundred years ago bridges were not supposed to carry floods; that when the floods came it was intended that they should go over the flat land, and not through the bridges. It would be found on examination that those bridges were broken-backed structures, generally with low land on both sides, the result of which was that the flood went over the low land, and the bridges remained. He agreed with Mr. Grantham as to the extreme importance of discussing the question solely on the basis of watershed areas. It was a mistake to talk about urban authorities, rural authorities and the like. A river should not be divided into little political divisions. As to the effect of drainage the Author had spoken very positively, but he should be glad to hear what reply Mr. Wheeler would give to Mr. Clare S. Read, who held diametrically opposite views. With reference to the Table showing the yearly rainfall at Boston from 1826 to 1880, if it were all one register it would no doubt be extremely valuable. He did not know that there was any serious difference arising from the changes which had occurred; but the Table was compiled from three or four separate registers, and it would be readily understood that differences in the gauge, in position, and in other matters, might prevent a strict comparison. Reference had been made to recent wet years, but he thought it was a question whether there had been anything exceptional in the rainfall of the last six or ten years. Mr. Wheeler's calculations showed that whereas in the five-year periods up to the last one the maximum was under 25 inches; and in the last period, 1876 to 1880, it was 29 inches. That, of course, was a considerable rise, and no doubt recent years had been very wet over the whole southern half of England; but he should not yet like to make any positive statement upon the subject. To determine the values for the whole of the United Mr. Symons.

Digitized by Google

Mr. Symons. Kingdom would not be a light task, but some rough averages, which he had calculated for England and Wales, bore out the theory of excessive wet during recent years. There was a dry period in 1863 and 1864, and then there was nothing remarkable until the wet year 1872. Two years followed with the rain below the average, succeeded by half-a-dozen rather wet years; but the excess in that period was not so great as the deficiency in the years from 1854 to 1858. As to the floods, he thought it probable that the values obtained at Boston would show a considerable excess during the last six years, because he believed the excess had been greater in the south of England generally, and especially in the south, east and central districts, than in the north and north-west. That was another illustration of the necessity for a thorough survey before any important steps were taken in the matter of conservancy. As to the Lancashire flood in November 1866, referred to in Mr. Jacob's Paper, his impression was that the flood represented, as had been suggested, a rainfall of 4½ inches over the area. Considering that the fall at one station was 3·90 inches, and that for the wettest stations the figures were not given, he thought it was not improbable that 4½ inches would be the actual amount. Mr. Hawkshaw stated that it was easy to define a flood level once for all; but it appeared to him that it was not quite so easy a matter. He did not know how it was possible to determine which was the greatest flood that ever had been or ever would be. In many Yorkshire and Lancashire towns a plan had been adopted which he should be glad to see followed out in the south. A number of flood-marks on brass plates were placed all over the town, and he thought it would be desirable that such a system should be more frequently adopted—that of placing permanent marks on permanent structures.

Mr. Tebbutt. Mr. CHARLES TEBBUTT supposed it must be admitted that, in order to keep the outfall and tidal channel of a river in a proper state, there should be a free admission of the tidal wave; but unfortunately that principle involved a difficulty at the point where the tide met the upland water in time of flood, if it was far inland. It did not matter so much when the land on each side of the river was at a higher level than high water at sea; but where, as in the case of the Great Ouse, 30 or 40 miles from the outfall a large area of land was below the level of high water at sea, tidal action was a hindrance to the discharge of floods from the uplands, and much suffering was caused by it. If the advantages gained by tidal action could be obtained with the existence of a sluice, to exclude the tide in time of upland floods, there would be an

Digitized by Google

improvement in drainage. Denver sluice greatly improved the drainage of the South Level, and Sir John Hawkshaw's new sluice that of the Middle Level. Why should there not be an attempt to combine the benefits of a sluice with those derived from a free tidal flow? The Grand sluice at Boston might be left open, so that there should be a free tidal flow when floods did not prevail. A sluice across a river, cutting off a portion of the tidal flow, need only be used when the drainage of the country required it. If there were a sluice across the New Bedford river, about 20 miles below Earith, so constructed as to permit the full tidal flow under ordinary circumstances, but closed during upland floods, so as to provide a receptacle for the upland water, an enormous relief would be experienced in the great task of draining the valley of the Ouse. Was it not possible so to construct a sluice across a portion of the tidal section of a river that the tidal flow should be permitted during those periods of the year (probably at least nine-tenths of the year), when no great freshes or land floods came down, and that, when a time of pressure followed, the tide might be excluded from that portion of the river required as a reservoir for the floods? Such an arrangement would not, he believed, lead to a deposit of silt below the sluice, as had been the case with the Grand sluice at Boston. It must be admitted that the sluice at Boston was a failure in the sense of causing injury to the river below, and being closed during a great portion of the year; but he should like the experiment to be tried of dealing with the sluice in the way he had suggested. If the benefits of a sluice could be obtained, and its evils at the same time avoided, it would solve some of the most difficult problems in Fen drainage. Mr. Tebbutt.

Mr. Baldwin Latham said there appeared to be great doubt as to the influence of tidal water in a river. He thought the principle laid down by Mr. Wheeler was a correct one. Certainly in all the main rivers the tide should be admitted; and perhaps no river in the country afforded a better illustration of that principle than the Ouse itself. When improvements in the river Ouse were carried out, over two centuries ago, the effect of cutting the Old Bedford River, and subsequently the New Bedford or Hundred-Foot River, was to shorten the old channel for the discharge of flood-water, and in consequence the floods descended more rapidly by the new and shorter channels, so that when they arrived in the lower part of the old river they ran backwards up the old channel above the point of junction and inundated the very lands these cuts were intended to relieve. Under these conditions the authorities erected Denver sluice, on the old River Ouse, above the junction of New Bedford Mr. Latham.

Digitized by Google

Mr. Latham. River, about the year 1651. This sluice at that time had three openings, each 18 feet wide, and the sill of the sluice was set 8 feet above the bed of the old river. After the construction of this sluice no improvement occurred, for the water descended by the New Bedford River and kept the gates of Denver sluice shut, with the same evil consequences to the lands on the old river above the site of the old sluice. To remedy this, Downham Eau, or St. John's Eau, a drain 120 feet wide and 10 feet deep, with a sluice at both ends, was made from a point above Denver sluice to a lower point in the River Ouse. In 1663 two additional eyes were added to Denver sluice, but this sluice was always the source of complaint as being the cause of the decay into which the river had fallen. It had been authoritatively reported that in 1645 the tides set into the River Ouse for five-and-a-half hours, but in 1660, after the sluice had been in operation nine years, the tide set in but three-and-a-half hours. In 1713 the two central piers of the old Denver sluice were carried away by the tides, and the tidal water once more entered the old river above the sluice. This accident proved no great advantage to the river, for the tides were throttled by the sluice, the opening through which, after its partial destruction, was but 70 feet wide, while the old river, before the erection of the sluice, was at least 120 feet wide at this point, and was also 8 feet deeper at the site of the sluice, for the foundations of the sluice remained intact; and subsequently the new sluice, constructed by Labelye in 1750, was erected on the old foundations. This sluice was re-erected in consequence of the complaints due to the silting up of the river above its site, and the consequent injury to drainage and navigation. The tidal wave acted by impulse; indeed, it might be said that it was like a pump making two pulsations daily. The effect of it was to carry the low water of the sea a number of miles inland. Mr. Redman had pointed out over and over again that, owing to the impulse of the tidal wave, low water in the Thames at London was absolutely lower than it was at Sheerness. That was a practical exemplification of what the impulse of the tidal wave would do in the way of drainage. If that tidal wave were excluded what would be the effect 20 miles from the sea? These rivers of the Fens had a very small fall; the smallest was 3 inches per mile; but if the tide were excluded, and the drainage depended upon the low-water mark of the sea, all the lands which now drained to as near low-water point as the sea level itself would have their low-water outlets raised by the distance which was necessary for the fall in the river from the sea to the place where the lands were located, or a place

Digitized by Google

20 miles distant, with 3 inches fall per mile, would have low-water mark raised 5 feet. It was therefore clear, from an engineering and scientific point of view, that the tidal impulse was an immense advantage to be made use of for drainage purposes. In order to get the full benefit of the impulse due to a tidal-wave, it was essential that there should be sufficient water in the channel at low water to transmit the impulse. This necessitated the rivers being made considerably deeper than was the case with the new Bedford or Hundred-Foot river, the bed of which was formed at 9 feet above the bed of the old river. Under such conditions it was no wonder that the full advantage of the tidal wave had never been secured in these districts. In the case of subsidiary drainage works it was necessary to put a sluice upon a drain, and make sufficient provision for the storage of water during the periods when the outfalls were tide-locked; but with regard to the main rivers there could be no doubt that the proper principle was to admit the tide. All the works in the Fens had been begun at the wrong end. There ought to be but one authority, having charge of all the drainage works within the natural watershed of the river, and its jurisdiction would naturally extend from the sea upwards. Works of improvement should commence at the sea and be carried on upwards, not as unfortunately had been the case in the Fen district, where the works had been commenced and carried out in a desultory manner in various portions of the districts, and where the outfalls at the sea were now being improved. The result had been that a large part of the expenditure incurred in connection with the interior works of drainage had not been so advantageously expended as it might have been if, in the first instance, the advantages of the improved outfalls had been secured. Mr. Latham.

Mr. GEORGE DAWBARN had had his attention directed to the subject for some years, and had arrived at the conviction, that the difficulties connected with the removal of the evils of flooding were not so much engineering difficulties as difficulties arising from the want of legislative facility for constituting right governments over the rivers. In many districts the proper course had been known for years. With regard to the Nene, for instance, for a century past Golborne, the Rennies, Stephenson, and Mr. Abernethy had all told the authorities what to do, but they could not do it, because there was no legislative system enabling them to carry out the works. The present private Bill system was utterly inapplicable and useless for the remedy of existing evils, and until a Conservancy Bill became law, like that proposed by the present Government, which was similar in principle to that introduced by Mr. Dawbarn.

Digitized by Google

Mr. Dawbarn. the previous Government, the evils would never be remedied. He was not looking at the matter as a professional man, but as a man of business. The necessity for passing such a Bill should be urged upon the Government. Delays would be sure to arise, and ample time would therefore be afforded to engineers for carrying out their arrangements.

Mr. Atkinson. Mr. W. ATKINSON observed that Mr. Jacob's Paper was an illustration of what had not been done in the improvement of rivers, and was a *primâ facie* case against the Government for not having passed laws making it compulsory that the rivers of the country should be properly maintained. Perhaps it would be impossible to find in England a district where floods were more destructive, and where they produced greater misery, suffering, and loss to the inhabitants. Mr. Jacob had pointed out that there had been various projects for a tunnel from Broughton through the Salford district to a lower reach of the Irwell. He admitted that the tunnel could not be used unless the lower reaches were improved, probably for many miles down; and that as yet there had been no project for that improvement. He had stated that the tunnel, by the introduction of sluice gates, could be used as an impounding reservoir, and so lengthen the period of flood; but it was obvious that if it were used without such a provision, that the lower reaches of the river would be more heavily flooded than at present. The effect of the flood in that district was much more serious than in ordinary districts, because the Irwell carried down with it such a vast amount of impure matter, so that the hay crops, if the floods occurred at the time of haymaking, were inevitably spoiled; they became saturated with impurities, and it took a long time for the land to recover its productive powers. Mr. Wheeler had pointed out that legislation had been very defective. The suggestions of Mr. Tebbutt seemed very appropriate. There must be considerable cubic content of river space, which, were the tidal water kept out, might receive the flood upland water. But it was a matter of detail and of special knowledge of each river; because, supposing that the extraordinary floods were at the level of the land, which was admitted to be about the level of high water, the dam and the sluices would be useless; on the other hand, if the level of the highest floods during the time of ebb were much lower, there would then be a large reservoir into which the flood-water could be taken. That idea seemed to have been recognised formerly. In the Minutes of Proceedings, volume xlv., page 80, Mr. Shelford stated: "The tidal capacity of the rivers on the English coast was always sufficient for the purpose of storing any

Digitized by Google

flood that might come down from the uplands if they were properly used." He was probably speaking of the Nene, with which he said he was well acquainted, and he therefore, no doubt, held some such view as Mr. Tebbutt. With reference to the question of legislation, there was evidently a conflict of opinion between the Authors of the two Papers, both having a practical cognizance of the subject, and it probably arose from the very different conditions existing. In the Fen rivers a great deal had been done. There were a great many authorities, and Mr. Wheeler did not see his way to disturb them. On the Irwell there seemed to be practically no authority; nothing had been done, and there was consequently a fair field for fresh legislation. As to the Rivers Conservancy and Floods Prevention Bill, the Government appeared to have no idea of making anything compulsory, taking upon themselves any authority, or doing anything for the rivers. All that they proposed was, that any twenty or more owners and occupiers, of whom at least one-half should be owners, and having in the aggregate a rateable value of £2,000, might apply for a provisional order to be appointed commissioners for the district which they might represent. That seemed to be making matters worse than they were. Mr. Jacob stated that nothing could be done on the Irwell, because there was no combination; but there was no greater chance of combination under such an Act than there had been for centuries. Mr. Wheeler stated that in the Fen district the great evil had been that there were so many authorities; and the proposed Bill merely opened the door for the establishment of a number of small subsidiary commissions. The purposes of the Act were, "The conservancy of rivers and the protection of land from injury by floods." The scope of the bill was not so extensive as it should be, because many small matters might arise for which no power was taken. In the case of the Irwell, for instance, the land adjoining the lower reaches of the river was seriously injured by the manufacturing products brought down from the town above; and it would only be justice and equity that there should be power in the hands of the Commissioners to compensate those who were thus injured. In the case of the Parret, steam tugs had lately been introduced to the detriment of the landowners, so that they had some difficulty in maintaining the banks of the river; and it seemed unfair that those who derived profit and benefit from the navigation of the river should not be held in some way responsible, and contribute to the maintenance of the banks. It appeared to him, therefore, that the Government scheme was inadequate and beside the mark. There should be some central authority having

Mr. Atkinson.

Digitized by Google

Mr. Atkinson. full power to direct everything that should be carried out in the conservancy and preservation of rivers. No doubt they could utilize the powers that at present existed. Boards of guardians had lately had thrust upon them an obligation to maintain the sanitary condition of the districts over which they had jurisdiction; and that had worked well in many districts; they had felt the responsibility cast upon them, and had in many cases, as honest and conscientious men, carried out extensive and valuable works. So, too, there should be some commission or authority in the country under the obligation of carrying out all river works.

Mr. Abernethy. Mr. ABERNETHY, Past-President,[1] remarked that the subject under consideration was one of national importance, which would no doubt soon occupy the attention of the legislature, and the practical observations which had been made during the discussion might be of assistance to the Government in framing a measure during the ensuing Parliament. The provisions of the Bill to which reference had been made would, he thought, little improve the existing state of things. The rivers in the Fens, discharging into the Wash, formed a type of a rather exceptional character, running through long flat districts, of no great importance as regarded navigation, but of great importance in the drainage of a large tract of country. Previously to the year 1629 the whole of the district, termed the Great Level, was subject to inundation; Ely, and various small villages and towns, at that time formed occasionally islands in the midst of an inland sea. It appeared that the authorities of that day had more enterprise than at the present time, for they brought over the celebrated Dutch engineer, Sir Cornelius Vermuyden, who recommended, in the case of the Ouse, two great cuts to be formed, one called the Old Bedford River, 75 feet in width and 21 miles in length; and then, some years afterwards, that not being found sufficient, the Hundred-Foot River. The Wash land, an extensive tract of land lying between these two cuts, was set apart as a flood channel. The result of Vermuyden's labours appeared to have been successful, for, on looking at some records of the year 1777 he had found a report to the Commissioners of Drainage, by a competent engineer of the period, who stated that, after the completion of the Hundred-Foot River, the works for some time answered their purposes. No complaints were made, and the projectors of the works and those who carried them out died in the belief that they had suc-

[1] In the interval between the reading of the Papers and the termination of the discussion, Sir William Armstrong was elected President.

Digitized by Google

ceeded in draining the whole district. But no proper jurisdiction seemed to have been established for the conservation of those works, and they were gradually allowed to fall into decay. The channels were allowed to silt up; the banks were not kept in repair; the Wash lands were used for the purpose of agriculture, and planted with trees; their original purpose was completely lost sight of; and in subsequent periods, to add to all these evils, at the commencement of the upper end of the Hundred-Foot and the Seventy-five Foot cuts an embankment was formed across the Wash lands, and a sluice was constructed, termed the Seven Hole Sluice—with openings of about one-half the sectional area of the river channel immediately above it. The result was that the country became more and more flooded, because the parties cultivating the Wash lands, having formed an embankment across the head of the Hundred-Foot River and the Old Bedford River, kept the sluice-openings closed, as at the present day, until the flood-waters ran over the banks of the river above; then only the shuttles were lifted and the sluice became useful for draining purposes. At the present day the river channel was deteriorating year by year; the necessity for drainage was increasing, and there could be no doubt that the existing state of matters was a disgrace to the legislature, if not to engineering. A suggestion had been made by Mr. Coote that the more tidal waters were admitted into the channels of the rivers the greater would be the obstruction to the passage of the water during floods; but the fact was that the *embouchures* of these rivers were all impeded with shoals. Little or nothing had been done to improve their entrances, it had been made a matter of reproach that Vermuyden while executing his works had neglected this important matter. The fact was that in the days of Vermuyden dredging operations were unknown, and there were no appliances by which sea-channels could be deepened without enormous labour and expense. What was required to overcome all these evils? First, the deepening of the sea-channels and the prolongation of training works, so that the current might flow seaward until it reached the deep water; then the removal of weirs or the construction of subsidiary flood-channels. No partial improvement of one section of rivers would be at all effective; they must be treated as a whole from their entrances to the upper reaches. So far as future legislation was concerned, it appeared to him that all the lands within the watershed of rivers should contribute in a greater or less degree towards the funds to carry out necessarily great works. He saw no other means by which the required improvements could be effected. The owners of the uplands no doubt

Mr. Abernethy.

Digitized by Google

Mr. Abernethy. thought it was hard that they should be taxed, but their superior drainage passed the water much more rapidly than in former days, and tended very much to increase the floods; so that they ought in justice to contribute something to remedy the evils which they themselves created. That was an outline of what he conceived was necessary to form the basis of future legislation with regard to rivers of that class. There were, of course, rivers of a different class, and the river Tyne, by systematic dredging from the entrance up to Newcastle had its low-water level lowered, the sectional capacity of the channel increased, and of course the flood-level also lowered. Reference had been made to the effect of placing a dam across a river for the purpose of excluding the tide during spring-tides. The flood-level in all rivers was almost invariably above the level of high water of spring tides, and during those tides the discharge was continuous. The action of the flood tide was, to a certain extent, that of a dam for the time being; but the adding another dam to keep up the flood-waters would only increase the area of the lands flooded; that would be the simple result, and it would also be placing in the channel of rivers barriers to the free flow of the tide, by which their outlets were maintained. He agreed with those who had stated that the great defect was divided jurisdiction. At present there was no authority competent to deal with rivers as a whole. He hoped that in any new measure provision would be made for a Board having complete control, not only over rivers, but also their affluents—a general Board composed of men selected irrespective of local influences. There were, of course, matters of engineering to be considered in connection with the regulation of rivers of a different type from those in a Fen district, namely, those flowing through a country with an undulating surface, or where the rivers had a considerable fall and great velocity. A great deal was required in such cases to preserve the banks from the action of flood-currents. He recollected, nearly forty years ago, a river in the north of Scotland, during a heavy flood, which injured its banks, and in some places completely altered its course. That river was brought back to its original channel by very simple works, viz., by groynes placed at an acute angle with the banks so as to deflect the current and lessen its action. In many cases engineers, after a river had changed its course, had been in the habit of fortifying the banks and maintaining it in the altered channel. That was the case with the Danube. Two hundred years ago it ran almost under the walls of the city of Vienna; a heavy flood took place, and at the high ground above the city the river was deflected considerably and formed a new channel. From that

Digitized by Google

time it was removed farther and farther from Vienna, and engineers had always maintained it in the new channels instead of bringing it back to its original course. It had since been taken in a straight channel close by Vienna, and the floods which formerly took place had to a great extent been ameliorated. Mr. Abernethy.

Mr. L. F. VERNON-HARCOURT agreed with the opinion expressed by Mr. Abernethy, that the whole river basin should be dealt with. He did not see how it was possible to devise a proper scheme without dealing with the whole of the basin. He thought also that the rating area should be co-extensive with the basin, a small rate being imposed on the uplands, and a heavy rate on the flooded area. Anybody who had had to deal with the question of the possible mitigation of floods must know what large works would have to be carried out, and how impossible it would be to raise adequate funds in any other way; because the flooded area was so small compared with the total area of the basin. He was well acquainted with the Witham basin, having gone there in company with Mr. Clarke Hawkshaw soon after the floods that occurred in the winter of 1877; and he might be permitted to refer to two or three points in the river that certainly needed amelioration. A good deal of flooding took place above Lincoln itself, being caused by the insufficient waterway of the Witham and of the Foss Dyke, the narrow openings of the bridges, and the obstructions to the flow of the river through Lincoln. Some low-lying portions of the city were inundated; and he was especially struck by seeing the flood-mark actually above the sills of the ground-floor windows of some houses which were being built near the Foss Dyke. The flood in and above Lincoln was considerably reduced by the bursting of a bank below. Mr. Vernon-Harcourt.

The river Witham was embanked from Lincoln to the sea. Though used for navigation through Lincoln, and below Bardney to its outfall, the portion between Lincoln and Bardney was devoted entirely to drainage, a lateral canal having been provided for the navigation early in the present century. If his recollection was correct, the lock at Bardney had no influence on the water-level of the river between Lincoln and Bardney. The banks between Bardney and Boston were solid and well formed; but between Lincoln and Bardney the embankment on the right bank was irregular in width and height, and was mainly composed of peaty soil, dug probably from the adjacent ditches and drains, and was very unsuitable for a river embankment. He was, indeed, more surprised at such a bank having stood fairly well than at its having occasionally failed. The

Digitized by Google

Mr. Vernon-Harcourt.

breach caused by the flood of 1876-7 was repaired with stiff clay brought from a distance in barges; and the contrast between the old bank on each side, and the new portion was remarkable. It seemed a pity that the clay could not be distributed along a longer length of bank, as the repair of the breach was like adding a strong link to a weak chain. The injury inflicted by the rush of water through the breach was indicated by the quantity of debris strewn along the embankment, such as gates, planks, wheelbarrows, turnips, &c., and even a wooden bridge.

The remedy proposed for providing against floods had been described by Sir J. Hawkshaw, in a report to the Witham Drainage Commissioners in 1877, and consisted mainly in enlarging the river channel, widening the Grand Sluice, and making a new cut for the Witham at Lincoln, so as to avoid the town and obtain a larger waterway and an additional fall for that portion of the channel. Unfortunately, the small fall obtainable between Lincoln and Boston would render the formation of an adequate channel, to provide against all floods, a costly undertaking.

He was glad to hear that the Grand Sluice was going to be enlarged, because it had not nearly so much waterway as the river above it. The effect of those sluices in stopping water was, perhaps, sometimes exaggerated; but when there was such a small fall in the river as there was in the Witham, it practically amounted to a lengthening of the river. He thought it might be said that in flood-time the river required a head of from 4 to 8 inches, in order to force its discharge through the Grand Sluice, and that would amount on the Witham to a lengthening of 1 or 2 miles. Below the Grand Sluice the river was in a bad condition through Boston, not, indeed, through any fault of Mr. Wheeler's, but on account of the various stagings that had been allowed to encroach upon the river, and no doubt also owing to the stopping of the tide at the Grand Sluice. It had been proposed by Mr. Williams, the engineer to the Witham Outfall Board, to make a new cut, leaving the river about ½ a mile below the Grand Sluice, and turning away from the town towards the outlet of Maud Foster Sluice, thus avoiding the great bend of the river round by the Black Sluice. That was opposed by the Black Sluice Commissioners, who foresaw that they would have to maintain the channel from the Black Sluice to the outlet of the new cut, and their opposition had been successful.

With reference to the effect of tidal flow, it appeared to him that it admitted of a simple explanation; the tide only flowed in when there was place for it. If the river was occupied by the flood-water

Digitized by Google

the tide did not flow in, and it therefore appeared to him that there was no objection to the tide flowing up a river as far as possible. In the case of the Clyde, where the tide had been admitted more than in any other river, what had the effect been? The low-water line had been lowered about 8 feet at Glasgow, and the high-water line had been certainly raised, but only about 3 inches since 1758. Again, on the Tyne, as Mr. Abernethy had pointed out, the low-water line had been lowered 2½ feet at Newcastle. On the Tees, also, at Stockton, the low-water line had been lowered 2½ feet; so that improving the lower part of a river and admitting the tidal flow was not injurious so far as flooding was concerned. Mr. Vernon-Harcourt.

He had had occasion to visit the Thames for Sir John Hawkshaw, for a report to be made to the Upper Thames Valley Commissioners, and he had gone over 150 miles of the main river and its tributaries. The general opinion at Oxford was that the flooding of the river there was due to the existence of Sandford Mill, and he had often heard it said that it would be a good thing if the mill could be bought up. However, it was not so much the effect of the mill, as of the sluice near the mill which was not nearly large enough. He had measured the sluices at the locks and mills all the way along the Thames from Little Wittenham up to Cricklade, and not one of them was at all equal to the waterway of the river.

He was occupied on the survey of the Upper Thames valley during the latter half of 1877. Floods frequently occurred on the Thames in the neighbourhood of Oxford, but he did not witness floods of any importance during his progress up the main river. He ascertained however that, at the part of the country he traversed, the flood-waters had been lying on the land for six weeks during the summer, owing to the absence of a sufficient outlet below, and had entirely spoiled an abundant grass crop, as well as the produce of arable land. That certainly was a state of things that ought not to exist. He found that the weirs and old stanches were all, without exception, inadequate for the proper discharge of the river; and the channel itself was very irregular in width and depth, and at several places had a very winding course. The upper portion of the river was greatly encumbered by reeds and other weeds, which filled up the channel in the summer, and when carried down by the winter floods tended to block up the narrow openings of the weirs. Most of the bridges also had very insufficient waterways. Low banks had been raised in certain places to protect the adjacent lands; but these partial protections only served to aggravate the floods on the opposite side of the river, and

Digitized by Google

Mr. Vernon-Harcourt.

below. No arrangements for cleaning out the channel, or regulations for opening the weirs, appeared to exist. The navigation, moreover, for which the locks and weirs were erected, had almost ceased between Lechlade and Oxford, except for pleasure-boats, so that the weirs along that part merely served to obstruct the flow of the river.

His progress up the tributaries of the Upper Thames, towards the close of 1877, was hindered on various occasions by floods, which afforded him special opportunities of noticing the impediments to their discharge. During a flood on the Evenlode, near Blenheim Park, he found a series of sluice-gates entirely closed. These sluices were far off from any houses and there appeared to be no one in charge of them. As he was anxious to obtain standing ground higher up along the river for continuing his survey, he got his boatmen to raise the sluice-gates, which increased the flood below and relieved the land above. On reaching a mill farther up the river, he was amused by the miller remarking that the flood below had passed off unusually rapidly. At this mill, having observed that the flood was high above, he searched for means of improving the discharge. He found a fish-trap placed across a portion of the river, close to the mill, which was almost closed up by the rubbish and leaves which had accumulated against the wire meshes. A little farther up he discovered some boards which had been placed on the top of the sill of an overfall weir to raise the water-level in dry weather, and had been left in place during the flood. By removing these obstacles the flood was considerably lowered. He adopted similar expedients for facilitating his progress along the other tributaries wherever the floods rose over the banks, and it was remarkable what an amount of relief the small means of removing obstacles at his disposal afforded. At one place a tree had become stuck under the arch of a bridge, and not only obstructed the waterway itself, but formed a nucleus for other rubbish, so that the channel had become almost entirely blocked up. At several mills, the millers were unwilling to open the sluice-gates to their full extent in flood time, for fear of reducing too much the head of water for driving their mills, owing to the rising of the tail water below, so that water was retained on the lands that might have easily been discharged.

It was sufficiently evident from these facts how entirely the river channels were neglected, and how a moderate amount of inspection, care, and control would suffice to ensure a more rapid discharge of the flood-waters in the upper parts of rivers. He, however, quite agreed with Mr. Wheeler in thinking that the whole river should

Digitized by Google

be dealt with; otherwise, relief of the upper parts would entail greater floods in the lower portions, and for this reason all works of improvement should be commenced at the lower end. Mr. Vernon-Harcourt.

These works would entail the reconstruction of all weirs on navigable rivers; and he was of opinion that, as stated in his Paper on "Fixed and Movable Weirs,"[1] the introduction of movable weirs would be of the greatest benefit for the control of floods. Those weirs would enable a river to be held up at any desired height in dry weather, for navigation or irrigation, and would leave the channel entirely unimpeded in flood time.

It had been pointed out by Mr. Jacob that the inclination of the River Irwell decreased towards its mouth. This was the case with all rivers; but the rate of the change of slope varied considerably, depending upon the inclination of the surface of their valleys. Thus rivers like the Thames and the Seine had a small fall throughout; whilst rivers rising in mountainous districts, and having a short course, like the Clyde, had a quick change of inclination.

Rivers might be divided into two classes, namely, torrential, and gently-flowing rivers. The first had a considerable fall, and flowed over impermeable strata; whilst the second had a small fall, and flowed over alluvial strata. There were, of course, rivers with tributaries belonging to both classes; and some rivers were torrential in the earlier portion of their course, and became gently-flowing rivers towards their outlet, as, for instance, the Rhine. The difference was important in treating of the question of floods, as the floods of torrential rivers were high, but of brief duration; whilst gently-flowing rivers had lower floods, but continuing for a long period and therefore more injurious. The accompanying figures (p. 288) showed the difference between the same flood of the Seine basin in the gently-flowing Seine itself and in its torrential tributary the Marne. Flood storage reservoirs had been proposed for torrential rivers, and might possibly be adopted with advantage where deep valleys, with narrow gorges, would admit of a large volume of water being retained by a short high dam. This system had, indeed, been partially adopted on the Loire; but the extension of this system on that river, and its adoption on the Yonne, had been rejected on economical grounds. The valleys of gently-flowing rivers were not suitable for storage reservoirs. The lands bordering on these rivers were too valuable to be devoted to such a purpose; and the long duration of winter floods would render such reservoirs

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lx., p. 24.

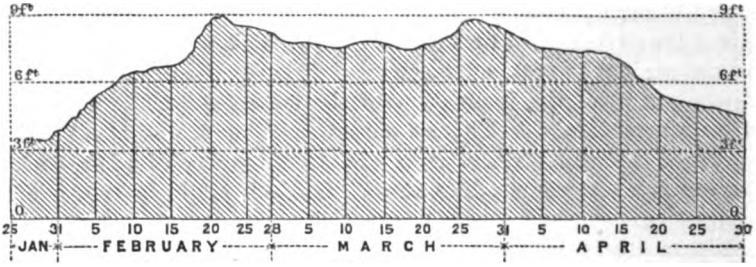
Digitized by Google

Mr. Vernon-Harcourt.

of little avail. It must suffice, in most cases, to provide against summer inundations; and high winter floods must be allowed to flow over the land, except where towns were liable to be flooded.

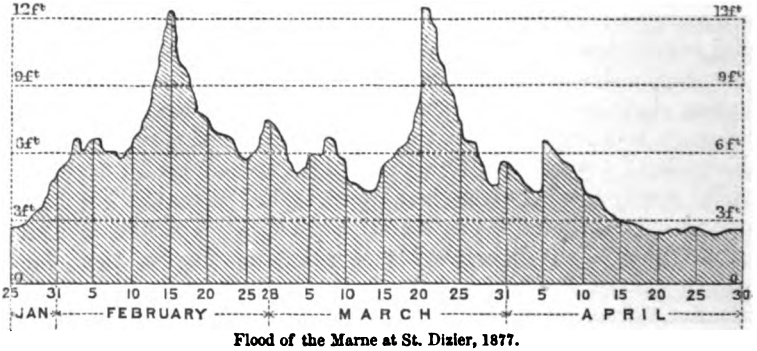
Warnings of the probable rise of a flood, gathered from rainfall returns and the rise of the upper river, had proved most valuable in France, and should be systematically adopted in England. He agreed with Mr. Jacob in considering that a river might be improved without annulling existing water-rights. It was commonly supposed that mills and weirs were the main causes of

FIG. 2.



Flood of the Seine at Bray, 1877.

FIG. 3.



Flood of the Marne at St. Dizier, 1877.

floods, and that their removal would be an effectual remedy. Though, however, the absence of mills and weirs would render the improvement of a river more easy, the purchase of the rights would be very expensive; and the channel itself would also need improvement, which would raise the total cost above reasonable limits. A great amount of the injury inflicted by mills and weirs was due to the insufficiency of their flood outlets, and to the control of the sluices being in the hands of private owners. If the waterways were enlarged, and the opening of the sluices made compulsory for certain heights of the river, it would be possible to avoid

Digitized by Google

the expense of buying out the vested interests; and all available funds could then be devoted to the improvement of the channel. The removal of mills, indeed, without an improvement of the channel, would only bring down the floods from the upper part of a river to swell the floods below. For instance, the river Cherwell, which flowed into the Thames at Oxford and had a very small fall for 10 or 12 miles from its mouth, had a much better fall higher up, on which portion several mills were situated. These mills led to the flooding of the lands above them; but if they were removed, these upper lands would be relieved, to the detriment of the flat meadows between Islip and Oxford, which even now were frequently flooded. This example indicated what injury a partial treatment of a river might effect. Mr. Vernon-Harcourt.

He thoroughly concurred with Mr. Jacob in thinking that each river basin should be under the control of a single Board; that the rating area should be co-extensive with the basin; and that, in the case of decided injury from floods, the improvement of the drainage should not depend entirely on merely permissive legislation.

Mr. JOSEPH LUCAS said that when he last heard the subject debated, it was more in respect of the administrative machinery proposed to be created by Parliament, than of the works to be carried out. On the present occasion, as might be expected, the debate had taken a more practical line. He did not mean to underrate the value of the information given in the Papers of Mr. Wheeler and Mr. Jacob, or to deny that in respect of the basins they described many most important facts were known; but he thought it was impossible with existing information to construct a complete map showing the hydrography of any one river basin. There were two points particularly affected by the want of evidence of that kind; first, the positions of the watershed lines or boundaries, which could not be drawn without special evidence, between any two basins where the boundary ridge consisted of chalk, for instance, such as the line between the Thames and Hampshire basins; and secondly, the question of the proposed mid-lands. It had been suggested by Mr. Hawkshaw that those lands should rank as mid-lands which might be 5 feet above the highest flood level. He (Mr. Lucas) had some records of the highest floods that had occurred within the last century on the river Nidd. Mr. Jacob had mentioned in his Paper that, on the 16th of November, 1866, there was a very heavy flood at Salford, known as "The Great Flood" all over England. According to records which Mr. Lucas had, it was not in 1866, but in 1868, that the highest flood Mr. Lucas.

Digitized by Google

Mr. Lucas. on the river Nidd occurred.[1] Floods had risen above a certain mark at a mill at Pateley Bridge only five times since 1777, and by far the highest flood was that of 1868. The height above the datum mark was 3 feet 6 inches. On July 6th, 1881, there was a very high flood, which only rose 6 inches above the same mark. At Castle Mill, at Dorking, which was a favourable place for registering high floods, there was a series of notches cut upon one of the posts in the mill, but unfortunately, though the height was registered, the dates were not given. He had, however, from a gentleman residing close by, the dates of two of those high floods, one flood last year, and one ten years before. How would it be possible to draw the lines that would be required to define the mid-lands in such positions as those indicated, or, indeed, in any position? He thought the proposal to form such mid-lands would be one likely to cause a great deal of discussion and be very difficult to settle. Mr. Vernon-Harcourt had mentioned that the waterways of many of the sluices

---

[1] River Nidd.—Extract from a letter from Mr. Robert Ingleby, of Pateley Bridge (dated October 20th, 1881). "Respecting our floods. We have this year covered up the door-check of our old mill. It has a great many floods marked on it. Previous to covering it up, we took the levels, and have had them engraved on the new stone doorpost of our present old mill. 'The Great Flood,' which was talked of as the largest flood in the memory of man by our fathers, was the 6th of May, 1825. It was quite local, all the rain falling in a very short space of time between Pateley Bridge and Ramsgill—none falling further up the valley—was severe and destructive. The flood of the 1st of February, 1868, was the largest flood ever known in this neighbourhood. It was up for several hours, and was 1 foot higher than the '6th of May' or 'The Great Flood.' It was 3 feet 6 inches deep on the mill threshold. [The 'Great Flood' in the Ure at Masham happened Feb. 2, 1882.]

Heights above mill threshold (engraved on stone doorpost).

	Feet.	Inches.
Feb. 1st, 1868	3	6
May 6th, 1825	2	6
Sept. 29th, 1852	2	0
July 4th, 1777	1	7
„ 6th, 1881	0	6
Nov. 28th, 1881	0	9

Since, or rather with the July 4th, 1881, flood, we have had, up to that of October 14th six floods all about a height."

River Wharfe.—Extract from notes made by Mr. John Leyland, of Kettlewell, Wharfedale.—"December 18th, 1869. On Saturday night the largest flood that has ever occurred since I came to live at Kettlewell, viz. ten years. We had to dam it out at both doors in the cellar. It reached the top of the gantry, and was about 3 inches higher than the flood of last February.—October 21st, 1874. On Wednesday night, 9 P.M., one of the greatest floods that has occurred since I came here, viz. for sixteen years. The water was 8 inches deep in the cellar, and 4 inches above the taps on the gantry. We had to draw the water out of both the front and back doors."

Digitized by Google

on the Thames were too small. Within the last four months Mr. Lucas had measured the waterways of a great many tributaries on the southern side of the Thames at all the mills, sluices and weirs, and had some of them gauged daily at several points, and he could state that the observation was equally true of the tributaries. The Castle Mill, at Dorking, might be mentioned as a good case in point, but it was only one out of a hundred similar instances. In that case the water rose several feet above the level of the mill dam, and the ordinary sluice-gate being in no way adequate to the ordinary flood discharge, the mill was regularly flooded every year. He had no desire to go back to the principle of centralisation; but he felt, if there was to be any thorough treatment of the subject so as to lead to a remedy of existing evils, there must be a central office to keep the machine going. He heartily approved of local autonomy; but in order to secure uniformity in regard to all the details of evidence which should precede the construction of any practical works, there must be a central office, and he knew of no better office for the purpose than the present Local Government Board. Mr. Lucas.

Mr. R. Rawlinson, C.B., desired to make a few remarks on river conservancy, having necessarily paid some attention to that subject. Mr. Wheeler, in his Paper, referring to the rivers which he had selected in the eastern and midland portions of England, stated that they did not rise at more than 300 feet above the sea at their sources, and that they flowed through a very flat country. They had been dealt with during the last century and a half under various Acts of Parliament, but only piecemeal, and the outcome of that kind of legislation was now apparent. Some members would probably be surprised to hear the number of Acts of Parliament which had been passed, and what little result had been obtained from all the legislation and all the money expended. He believed he was right in saying that the various public and private Acts of Parliament relating to rivers, canals, harbours, and docks numbered about four thousand. If the outcome that had been explained was the result of all that legislation, it was high time to look for something more effective. Rivers in a civilised country had two purposes to serve, which were in some degree antagonistic. Those who used them for navigation wished to put them in an effective state to accomplish that purpose; those who wished to prevent land flooding would act in a different way; they would not care much about the navigation if floods could be kept from their lands. But there, again, the question was complicated. There were riparian owners who would be glad to have floods kept Mr. Rawlinson.

Digitized by Google

Mr. Rawlinson. off their land if they had not much to pay for it, while others would say that if the floods were kept off their lands they would be seriously injured. The proposition had been to prevent floods by making reservoirs, and it had been stated that in some continental countries that system had been tried. He could only say that any engineer who made himself acquainted with meteorology, and with the volume of water that came down in excessive floods, would soon abandon the idea of forming impounding reservoirs to prevent flooding. Mr. Wheeler had stated that the rivers going through a comparatively flat country formed low-level reservoirs now, as occasionally there were flooded areas of 3,000 and 5,000 acres in extent. That, he thought, in some degree tended to settle the question of reducing floods by impounding reservoirs. In giving evidence before a Parliamentary Committee he had laid it down as a general principle that one prime remedy for limiting the area of extensive land-flooding must be embanking, and he knew of no other. To resort to general dredging would be attended with such enormous costs that only an exceptional river could bear it, and no agricultural riparian owners would submit to it. Nor would excessive floods be prevented by dredging. The Clyde had been referred to as a capital example of a river of a certain class that had been improved by dredging. It had been a sort of will-o'-the-wisp to engineers. They ought to take into consideration all that the Clyde had to do and all that it was dredged for and prepared to do. It had above it the lowland area of Scotland, most productive in iron, coal, and manufactures; it had also, after London, one of the largest and wealthiest cities in the empire—Glasgow—to accommodate with its shipping, and therefore the persons resident in that district could afford to pay the enormous costs required for dredging, and the large annual sums required to keep the river open. If the trade and the revenue were withdrawn, and the dredging discontinued, the Clyde would rapidly go back to what it was before man took it in hand. In the course of a discussion on the Suez Canal question, some members contended that the canal could not be constructed, while others admitted that it could, and that it was only a matter of expense. He remembered remarking on that occasion, that of course the Suez Canal could be opened and made fit for navigation, but that there was one penalty its makers would have to pay in perpetuity —they must never cease dredging. In the portion of the canal running through alluvial sand the banks would unceasingly subside, and the bottom unceasingly tend to come up. There was certainly not a month, scarcely a week, that the canal was not

Digitized by Google

impeded by some large vessel going aground. He agreed with a previous speaker that English rivers were in a disgraceful state. It behoved the Government, therefore, to take up the question of river conservancy in earnest. How could any general and permanent good be done if they permitted things to go on as they had been going on up to the present time,—if they permitted private Acts to be multiplied, and private interests to rule rather than the general good of the whole watershed? Large river basins should be treated as unity for general improvement; but small rivers should be grouped. If any good was to be done by legislation, there must be local unity, and there must also be a central body. However centralisation might be repudiated, in some cases it was necessary. There should be local authorities for rating purposes. Rivers could not be improved without rating, and the local authorities should therefore be representative; they should be elected, and have an interest in the work to be done. When the local authorities and the central body were established, no riparian owner should be permitted to do any serious work at any part of a river without submitting his plan to the authority governing in his district. If a dispute arose between him and the local authority, he should have power to appeal to the central authority, and that central authority should have power to send down an inspector to examine and report, and the central board should afterwards have authority to decide the local dispute. Thousands and tens of thousands of pounds had been spent in litigation, because there was no one to step in and decide authoritatively as to what ought or what ought not to be done. Three reports had been made upon Rivers Conservancy by Mr. John Thornhill Harrison, M. Inst. C.E., and himself, as Royal Commissioners, on the Thames, the Lee, and the Aire and Calder. They had gone fully into the question, and had found that there were the difficulties to which reference had been made. All through England what might be termed riparian manufacturers were in the habit of casting refuse, without any consideration but of self, into the stream; ashes were thrown from the factories, scoriæ from ironwork, rubbish from quarries, road scrapings from roads, and the result was that the floods carried the detritus down, levelling the beds of the rivers, and so lifting both the low-water and the flood-level, tending to increased flooding of adjoining areas, agricultural and urban. In the course of their inquiry in Yorkshire, on the Aire and Calder, a flood came down those rivers which caused, at the lowest calculation, damage probably to the amount of more than a million sterling. The floor of one large mill, which they inspected, had been filled 5 feet deep

Mr. Rawlinson.

Digitized by Google

Mr. Rawlinson. with silt, and all the carding engines were spoiled. The owner said that that was the third time he had suffered in the same way within the last twenty years. In some other cases, as at Leeds, the water was up to the bedroom windows, and they saw boats taking provisions to the poor people, who would not leave their houses, fearing lest they might be robbed before they got back again. In their report of the Aire and Calder they had mapped out what they considered would be a proper jurisdiction for such rivers, towns, and manufactures. An agricultural river going through a purely agricultural district, should be dealt with differently. In regard to the Aire and Calder, they had mapped it out in sections of watersheds. Taking the principal town in the district for that special area, they had said, "There is a Local Board, having a surveyor, and you might give him, as an additional duty, the inspection of that special part of the river." But all the rivers of the kingdom should be under one jurisdiction centred in the metropolis, with a Cabinet Minister at its head. And if Parliament could not see its way to establish a jurisdiction something upon that basis, it had better leave the question alone. It was not pleasant to see hundreds of acres of some of the table-lands of England under water after a few days' heavy rain, simply because of defective arterial drainage.

Mr. Wheeler. Mr. WHEELER, in reply upon the discussion, said the first question requiring reply was as to whether there was anything exceptional in the throttle which affected the tidal flow in the Nene. He thought that there could be no doubt about this, and that if the river were improved by the removal of the impediments at Wisbech, the tidal wave would be more regular in its action. Attention had not been directed to this as something uncommon, as would be inferred from the remarks made by Mr. Bateman, but simply as an incident in the history of the river, and as a rather exaggerated example of tidal action that pointed to irregularities which might be modified by improvement. With reference to Mr. Shelford's remarks as to bars at the mouths of rivers discharging into the sea being caused by cross currents, and not by any conflict of the ebb current and flood, he perfectly agreed that it was frequently the case, but the rivers here referred to could hardly be placed in the same category as those in a natural condition flowing into the sea. Here the rivers discharged through confined channels which terminated in a sandy estuary, and the conflict, which took place between the incoming and outgoing current at the mouth of the confined channel, prevented the free action of either at that particular point, and hence the tendency of the

Digitized by Google

sand to accumulate. After a certain amount of accumulation the outgoing current, on leaving the confined channel, becoming spread out, and its power dissipated was insufficient to remove the obstruction, which gradually extended, and the only remedy for which was the gradual prolongation of the training. The question raised by Mr. Coote, as to the effect of the improvement in the action of the tidal current on the discharge of the fresh water, had been answered by Mr. Shelford, Mr. Baldwin Latham, and others. Mr. Tebbut, however, pursued the question further, and while admitting that the general effect of a sluice or other obstruction to the free flow of the tidal current was detrimental to a river, asked whether such a sluice could not, by being brought into requisition only in exceptional times of extreme floods, be beneficial by excluding tidal water and so leaving a reservoir for the fresh water to continue to flow into during the rising tide, so that the fresh water, instead of being headed up by the inflowing tide, would continue to flow downwards until level with the tidal. To those who had not given much attention to the continued action of tidal waves, such a scheme appeared feasible, and was held to be so by many persons interested in the Fen drainage. The error arose from regarding the action of the tidal current as the same as that of the fresh water. The latter was a current always flowing in one direction, downwards towards the sea, deriving its motion from gravity. The tidal current was due to a wave action, an alternately progressive and retrogressive motion, incited primarily by the momentum of the tidal wave generated in the ocean, thence imparted to the water in the bay or estuary which gave the impulse to the tidal wave up the river. The same action which took place on the shore where the tide was seen to advance, not by one continuous flow but by a series of waves which alternately advanced and receded, but each time made some progress forward, occurred in the propagation of the tidal wave, only the wave was longer and more continuous with reaction proportionate to its action. If this wave was arrested in its career it was robbed of its reactionary force just as a pendulum, stopped in the middle of its swing, would not return with the same force as that with which it started. So if, by a sluice placed across the channel of a tidal river, the action of the tidal wave was stopped, the downward movement of the water on the receding of the tide would be proportionately sluggish, and the tidal wave would swing back again with decreased energy. It was due to this wave-like action that it would frequently be found that the low-water mark in a river or estuary was actually lower than in the sea into which they discharged, as instanced by Mr. Redman in the case of the Thames,

Mr. Wheeler.

Digitized by Google

Mr. Wheeler. and as was the case in the estuary of the Wash. If the tidal wave was impeded, and the fresh water allowed to level itself up, the benefit of the low-water level of the trough of the wave was lost, and, further, the pace of the down-flowing current in the upper reaches of the river would become lessened, due to the action in the lower or tidal reach having been converted into a mere subsidence of the water instead of a return tidal wave. While the tidal swing of the wave was arrested by the sluice, and the water slowly rose outside, the water on the inside was also rising until it attained a horizontal position, the surface of which was of the same height as the water on the outside. The river had been converted from a flowing stream into a lake, and on the recession of the tide the wedge-shaped mass of water thus accumulated must pass away before the river again attained that inclination of the surface to which its downward course was due. This influence must extend several miles up the river, and there would not be time between the tides for the water to attain the natural inclination due to the condition of the channel. Now as the discharge of a river, other things being equal, was in proportion to the head or inclination of the stream, it would be seen that any supposed gain from the reservoir which the wedge-like mass of water above the sluice had given was more than compensated by the decreased pace at which the water would flow due to the loss of head. He would take the Witham and the Ouse as examples. In the Ouse the tidal wave had a free course and the water ebbed out sufficiently low to create an average inclination in floods of about 9 inches in the mile from Denver Sluice to the estuary. In the Witham where the tidal flow was arrested by the Grand Sluice, the low water only ebbed out sufficiently to give an inclination of about 3½ inches per mile from Bardney to Boston, where the tide was stopped, a distance of 22 miles. The gain in the discharge by the removal of the sluice and the lowering of the low-water mark would be an immense advantage to all the districts draining by this river. Mr. Symons had quoted the opinion of Mr. Read to prove that the views generally entertained that pipe-drainage and steam cultivation had been one of the principal causes of the floods of recent times were erroneous, contending that the soil being rendered more porous and drier by these operations, it was therefore in a state to receive more water, just as a dry sponge would absorb more than a wet one; but it should be borne in mind that floods followed after a continuous downfall of rain, from which the dry earth became soon saturated, and when in this condition parted with any surplus more rapidly than undrained land, from the facilities which drain-pipes and clean outfall ditches gave to the discharge of the water.

Digitized by Google

If the land was undrained and not broken up by cultivation the rain lodged on the surface and in the furrows, and slowly found its way by ditches choked with weeds to the river. Mr. Wheeler.

Mr. JACOB said that Mr. Bateman and some other members had urged that every river should be treated on its own merits, and it had been fairly remarked that the Irwell and the Fen rivers might be taken as representing the top and the bottom of a series, and that almost all rivers would come under one of those two classes. It had been suggested that the floods could not be stopped, but he would shrink from such a conclusion. As engineers they must all feel, if they had any self-reliance, that floods must be stopped sooner or later. Of course difficulties would present themselves, and if there were any districts where greater difficulties would occur than in others, they would be those of the Fen rivers, where tidal waters had to be encountered, and very flat inclinations to be dealt with. He thought the system of contour channels would be impracticable in the valley of the Irwell. The form of the ground was such that such channels could answer no useful purpose. The relief tunnel was not, as suggested by Mr. Atkinson, intended to act as a reservoir, but simply to remove the surplus water, and carry it by a short cut clear of Manchester and Salford, and thus to deliver it into a part of the channel where flooding could easily be controlled by embanking. The reason the Irwell would have to be relieved by an underground channel was that it was completely throttled at a point below Sherborne Street Bridge, and the water was delivered to this point much more rapidly than it could pass along the channel lower down the stream. All the injury from the flooding of the Irwell proper took place in Lower Broughton and the Adelphi, and there was no remedy but to cut a relief channel from C, say to D, or below that point. The objection raised to the construction of such channels was illusory. People lower down the river at Warrington, Eccles, and Patricroft said, "What are you going to do with this channel? Do you propose to flood us out more completely than before?" A channel of that sort, when properly sluiced, would have no such effect. It would simply discharge the first part of a flood, if it was a sudden and a short one, more rapidly, and so relieve the natural channel; but in the case of any long flood, as far as the lower districts were concerned, it would have no effect. In the lower districts, and in the open country where embanking could be employed, he felt confident that the evil could be cured easily and economically. It was only a question of money, and that pointed to the spreading of the expenses over the whole watershed. Even in Manchester or Salford, or if both Mr. Jacob.

Digitized by Google

Mr. Jacob. together were to combine, the rate would be so heavy that in all probability no application to Parliament for the necessary powers would be attended with success. In the Salford district alone it would require a rate of a shilling or sixpence in the pound, to which the ratepayers would not submit. They would rather endure being flooded than pay such a sum; particularly as the people who would not suffer would exceed in number those who did suffer, and no plan would be adopted of such a costly character. It was absolutely necessary, therefore, that large areas should be embraced in conservancy districts, and he thought that no safer boundary for such a district could be taken than the watershed area. When considering the question of taxation for the improvement of rivers, it was of course impossible that everyone could be charged in anything like direct proportion to the amount of benefit which the improvement of the river would effect, and it was evident that many who would have to pay would derive no direct benefit whatever. It was to be hoped, however, that the legislature would make provision for distributing the taxation as equitably as possible, and that the fact would not be disregarded that there were navigation companies, mill-owners and others, who would probably derive more direct benefit by the improvement of such a river as the Irwell than any other interest concerned; whilst, unless some special provision was made, such parties would have no more to pay than the great mass of the owners of property in the low-lying districts. If rivers were dredged, scoured and straightened, no doubt a considerable saving would accrue to those companies which now had to keep the navigation open at their own cost; and it was obvious that the removal of silt and the widening of river channels must have the effect of increasing the storage of water for mill purposes. Much injury had resulted from the construction of solid weirs on rivers, and flooding had been much increased by the consequent raising of the river beds. It was therefore but equitable that in apportioning the taxation, those properties which derived direct pecuniary benefit from improvements should not be lost sight of.

Mr. Marten had pointed out what at first sight appeared to be a discrepancy between the gaugings of the river during the great flood of 1866, and the recorded rainfall during that flood, but there was really no discrepancy. The 24,000 cubic feet of water per second which undoubtedly passed down the channel represented a rainfall of $4\frac{1}{4}$ inches in depth over the whole area of the watershed, whilst the greatest rainfall recorded at any station in the valley on the day of the flood was 2·70 inches; but there had

Digitized by Google

been heavy rain for the three days preceding this date, and no doubt all the subsoil drains were discharging freely. Moreover, it was probable that the fall of rain for a few hours immediately preceding the time of maximum flood was much heavier than the average rate of fall for the whole twenty-four hours. Mr. Jacob.

Mr. Rawlinson's remarks regarding the relative advantages of dredging and of embanking were well worthy of attention. Evidently there was a limit to the amount of dredging that could be executed through districts in which the margin of the river was bounded by large and costly buildings; for any interference with the foundations or footings of the walls would certainly be attended with danger to such structures. One of the most formidable difficulties to be contended with as regarded the dredging of the Irwell had been to find suitable and sufficient places of deposit for the material. At a seaport the material could be sent out to sea and dropped in deep water, but this was impossible in many localities, and the only remedy was to improve the sections of the stream, both cross and longitudinal, so that a velocity would be obtained which would carry the silt down to the estuary. The removing or reconstruction of existing weirs, and the straightening of the river's course, combined with the formation of substantial and sufficient embankments, would undoubtedly accomplish the desired end.

Correspondence.

Mr. Walter R. Browne was anxious to say something in support of Mr. Wheeler's views as to the cause of floods. About 1868 he had been engaged, under Mr. Thomas Howard, M. Inst. C.E., in investigating the conditions of floods in the River Tone at Taunton, which had been greatly complained of. This investigation led him to conclude that the floods had certainly become higher and more serious in recent years, a matter which Mr. Jacob appeared to doubt; and that the greatest obstacle to the flood waters being successfully carried away as they rose lay in a succession of mills, which had been long established near the town. He trusted that, in any legislation on the subject, the claims of mills would be closely inquired into, and summarily disposed of in some way. The importance of such mills, for grinding the corn of the district, had long ceased to exist, and with it the need for any special protection. Being mostly placed on shallow rivers, with little fall, the wheels had to be wide and cumbrous; and the consequent loss of effect, with that which arose in the bringing up of their slow motion to the speed required for grinding, made them in most Mr. Browne.

Digitized by Google

Mr. Browne. places less rather than more economical than steam power. At the same time their evil effects on the river, from the contraction of the waterways, dwelt on by Mr. Vernon-Harcourt, were very serious. In Ireland he had seen a few roofless walls marking the site of an abandoned mill, with nothing left in an efficient state except the weir; and this weir, by keeping up the water-level, was drowning and rendering useless many hundred acres of the richest meadow-lands bordering the river for some miles above. Yet if any one had set to work to remedy this by breaking down the weir, he would no doubt have been met and stopped by some vested interest in the ruined mill, powerful enough to perpetuate evil, though utterly powerless for good.

He ought perhaps to advert to a sentence in which Mr. Wheeler spoke of having been led to an opposite conclusion to that set forth in his own recent Paper as to the effect of tidal scour. That was almost the only sentence in the Paper with which he did not agree. He did not see that there was any substantial divergence between their conclusions. Mr. Wheeler, in the same paragraph, stated that the silting up of the Fen rivers was due to "the sand carried up with the tide;" and also that "in summer, when the fresh water is small," this silt remained instead of being swept away; and then went on to say that it was desirable to remove all obstructions, &c., so as to make the run up and down as rapid and unimpeded as possible, and so reduce the deposit to a minimum. Therefore, Mr. Wheeler endorsed Mr. Browne's conclusion that the entrance of tidal waters into such rivers was nothing but an evil, and only insisted that, if they did enter, they should be allowed to run in and run out as rapidly as possible—a proposition with which he cordially agreed.

There was one other sentence with which he was not satisfied, and that was where Mr. Wheeler stated that the quantity of water at spring tides was six times as great as at low water, and must therefore have a greater effect. Now this practically meant that the river was much deeper at the top of the tide than at low water, say 15 feet deep instead of 5 feet; and he would ask Mr. Wheeler to explain in what way he considered that the water in the upper 10 feet was able to operate in producing scour upon the bottom of the river, which was 5 feet further down. He had himself given reasons[1] why increased depth should diminish the scour at the bottom, but he failed to see any reason why it should increase it; and it was time that the numerous engineers

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxvi., p. 84.

Digitized by Google

who appeared to take the latter view should give at least some ground for their opinion. Mr. Browne.

The Rev. J. C. CLUTTERBUCK remarked that the frequency of floods, and the damage caused by them, had been put forth in proof of the necessity of placing the rivers, as main arterial drains of the watersheds of England, under Boards of Conservancy, armed with legal powers to carry out remedies for acknowledged evils. It was obviously impossible to devise a scheme by which all rivers and their watersheds could be dealt with alike. Take the watershed of any river, and it would not be found practicable to calculate the flooding capabilities with reference to its measured surface area, due to its geological condition. In the chief rivers finding their outfall in the Wash, as in all cases, the geological condition varied. So, in a remarkable way, the Thames in its upper district gathered its waters from the springs of the chalk, and oolitic, and liassic strata, and the surface waters of the Gault, Kimmeridge, Oxford and Lias clays. These latter were to a great extent covered with sand and gravel, in which the water accumulated, from the surface of which it would not flow, and whence floods were not augmented except in some instances of artificial drainage. Rev. J. C. Clutterbuck.

It was evident that the Conservancy of the Thames, except in the case of the pollution of its tributaries, did not extend beyond the main stream, of which, for the purposes of navigation, mill-power and the supply of water to London, it was the guardian. It was to be regretted that until lately the riparian owners represented by the Thames Valley Drainage Act, had not availed themselves of the assistance which the Thames Conservancy alone could give.

Much had been done of late years to repair the neglect and dilapidation which had accrued before the Upper Thames was placed under the care of the present Conservancy Board. In the existing condition of the river and its watershed, little could be done permanently to regulate the floods and hinder the mischief caused by them until the riparian owners of property improved the drainage and increased the carrying powers of the tributaries and their watersheds. Take, for instance, the district known as Ottmoor on a bed of the Oxford clay, naturally drained by the River Ray, a river passing over a flat surface sometimes so reduced in volume as to be nearly dry, so that no mill had been built upon it, yet frequently flooded, and scarcely at all relieved by the Cherwell, into which it flowed at the village of Islip. Thus the floods were protracted and stagnated on a soil rendered almost valueless from these causes; the Conservancy of the Thames had

Digitized by Google

Rev. J. C. Clutterbuck.

no power to remedy the evil, nor was it reasonable that they should have it.

There were other districts drained by the Evenlode, Windrush, and smaller streams above, or the Ock, the Thame, the Kennet, the Loddon and Coln below, which in a perfect system would need improvement, as they more or less contributed to the flood waters of the main stream, though some of these mainly depended on the springs of the Chalk stratum for their supply.

There was a general impression that the volume of the floods in the Thames had been increased by the extension of agricultural land drainage; but the record of the height of recent floods as compared with those of fifty years ago, under similar conditions, did not favour that impression.

The soil, which on an average would absorb one-fourth of its weight of water when dry, even in the winter gave off a considerable amount of moisture by evaporation; this must be replaced before any moisture could descend to the water bed, or point at which the soil was surcharged with water. That which Mr. Wheeler said with reference to the different amount of rainfall, by which the summer floods were produced, rather favoured this view; the absence of flood was due to the small amount of rain in the month of June 1867, preceding the July in question, twenty-four days from nearly the beginning of June to the end of that month having passed without rain. Whereas the heavy freshets in July 1872 and the flood of 1880 were preceded by wet times; in other words, the absorption of the rain in one case, and the previous saturation of the soil in the other, accounted for this. So in 1868, May, June, and July, months with great evaporation from the soil, had less than half the average rainfall, leaving a large amount of water to be replaced by the autumn rains; hence it was that, notwithstanding the prevailing impression to the contrary, land drainage did not augment the volume of the floods to the extent supposed. This too was borne out by the experience of many years. When the soil was water-logged, evaporation was not so rapid as when the water sank into the surface. When the surface was surcharged with water every shower came away in flood, whereas in drained land the rain-water must first replace that evaporated, which tended to decrease the amount given off by drains. The action of a Board of Conservancy should as far as possible be confined to the main stream; without this was duly attended to, the relief of the whole watershed could not be fully carried out. No expense should be spared by the riparian owners to give vent to the water of the tributaries, often allowed to stag-

Digitized by Google

nate on the surface of the soil, by which floods were protracted, and great damage done to the district where these floods prevailed. Rev. J. C. Clutterbuck.

Mr. L. Gros, Inspector General of Roads and Bridges, had been much occupied with this question in France, principally in connection with the improvement of rivers as navigable channels, and the means of preventing damage from floods. He had also acted as president and reporter of a commission of engineers appointed to inquire into the causes of the disastrous floods in the Theiss at Szegedin in 1879,[1] and to suggest means for preventing their recurrence. He thought that the recommendations of that commission would be of interest in connection with this discussion, and therefore begged to present to the Institution a copy of the report, from which the following particulars were gathered. Having obtained the most exact information extant as to the height reached by the water in the greatest known floods, the commission made a careful study of the regimen of the river, and also examined a large number of embankments, some of them in process of reparation or of being raised. It was found that the method of repair, as well as that of construction, was in general very imperfect, and that the banks were nearly everywhere of insufficient thickness. But the greatest default was in the too-contracted width of the channel between the banks, and in the mode of carrying out the works by different companies, who acted on the principle of following the course of the stream, and of reclaiming in their sections as much land as they possibly could, without having regard to the system most beneficial for the river as a whole. Mr. Gros.

In view of these facts the Commission were of opinion that the widening of the river where it had been unnaturally contracted should at once be proceeded with, and the obstructions caused by plantations of trees in many cases bordering the outer sides of the training banks should be removed. The banks should be widened so as to give in all cases a top surface of at least 23 feet broad (instead of from 6½ to 8 feet), and they should be maintained at a height of not less than 1 metre (3·28 feet) above the highest known flood. The augmented width of the banks might be utilized by converting them into roads which would to some extent neutralise the attacks of noxious animals such as moles, whose ravages were a fruitful source of failure in ordinary banks. The present system of benches adopted for strengthening the inner slopes of the embankments was commended as excellent, and it

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lix., p. 381.

Digitized by Google

Mr. Gros. was suggested should be everywhere adopted. More attention should be paid to the effectual grassing of the slopes, which at present was left pretty much to haphazard. The inclination of the slopes was a point of capital importance; it was recommended that this should be as gentle as possible on the river side, say, 1 in 3, and 1 to 1 landwards, both for the main bank and the bench. The maintenance of the banks, now carried out in a perfunctory manner by various interests, should be systematised and placed under the immediate control of the Government. In order better to preserve the banks against the sudden effects of floods, the system of warnings followed on other great rivers should be introduced. The desideratum was that the companies or persons interested should understand, once for all, what was necessary to be done when they received notice of an expected flood. Finally, the Commission attached great importance to the adoption by the superior administration of more stringent supervision of the local companies. It was absolutely necessary that all these bodies, without exception, should submit any plans for isolated improvements to competent engineers appointed by the Government, who would exercise their functions in the interests of the whole valley. It was further to be desired that the execution of new works designed for local requirements, as well as the maintenance of those existing, should be under the surveillance of government inspectors having full powers.

With regard to the mode of raising the funds for carrying out future improvements, it was suggested where, as occasionally happened, the means of some of the societies were not equal to their share of the work, a general levy on the funds of all the associations should be made to supply the deficiency, or that a modification of the system followed in France should be introduced, whereby the surplus cost of necessary public works in departments too poor to pay the whole was defrayed by subventions from taxes levied on the departments in general.

Mr. Gros also presented to the library of the Institution a book of the official regulations adopted in France for working the system of flood-warnings; and a copy of a memoir by himself on the insufficiency of impounding reservoirs to cope with floods. (Abstracted in the Minutes of Proceedings, vol. lxvi., p. 408.)

Mr. Hagen. Mr. G. HAGEN observed that of late the opinion had been expressed by some engineers, when exceptionally high or very low water had been observed in rivers, that the cause was the always increasing extent of cultivation. The felling of forests, the drainage of marshes, and the numerous larger and smaller

Digitized by Google

drainage channels necessitated by agriculture, caused a more rapid flow of the rain to the rivers than previously. Hence the rivers were at times more copiously supplied, and afterwards, in periods of drought, less copiously. Experience showed this phenomenon without doubt in many little brooks so markedly that the action of cultivation in the matter could not be mistaken. From this it had been assumed that the same consequence must follow in the case of larger rivers, and that provision should be made lest the further extension of cultivation should occasion the greatest dangers, partly from the more extensive flooding, and partly from the shrinking of the river discharge. Mr. Hagen.

In the Parliament of the German Empire two years ago this was alleged as an undoubted fact, and the Government was requested to consider this imminently increasing danger. Shortly before, the same opinion was expressed in the Academy of Sciences at Vienna; and the Royal Academy of Sciences in Berlin, and those at Copenhagen, St. Petersburg, and perhaps elsewhere, were invited to consider how the evil could be obviated. It was remarkable, however, that the Vienna Academy based this invitation, not so much on experience gained in Austria, as on the Prussian observations of the water-level of rivers.

This led him to investigate whether the observations made for a long time daily at numerous stations on Prussian rivers, and carefully tabulated, furnished such a result. The Minister of Public Works willingly gave him permission to consult and make use of the tables of water-levels deposited with him.

It ought not to be left out of consideration that before 1846 the invariability of the position of the "Pegel," or scale, on which the height of the water-surface was read, did not always receive the necessary attention. It appeared, then, that one of these scales had been raised, during about ten years, by degrees, about 2 feet, probably by the ice; it consequently indicated the water-level much lower than before. In consequence of this observation, it was arranged, in 1845, that the scales should be compared from time to time, and at least annually, by careful levelling with different fixed points in the neighbourhood, and that when marked differences were found the scales should be readjusted. The earlier observations could not, therefore, be taken as trustworthy, and were only used if other circumstances confirmed the record. This was fortunately the case with the scale of the Rhine at Düsseldorf, which was cut on an old but still firm wall, and had been observed daily since the beginning of the century.

He chose for each of the principal rivers two stations, which were

Digitized by Google

Mr. Hagen. most convenient for the purpose, and found for these, or calculated for each year of the whole period during which the observations appeared satisfactory, both the mean, the absolute highest and the absolute lowest water-level. Then he inquired by a methodical proceeding, in which all the data were assumed to be equally valid, whether a progressive raising or lowering of the water-surface could be inferred with safety, or with a certain probability. He must remark that none of the stations was exposed to the influence of the flow and ebb. The result of this research he laid before the Academy,[1] and it had been published in the volume for 1880. Two other reprints of it had been issued, besides an abstract in the Zeitschrift für Bauwesen.

It appeared that in general, during the period of from thirty-four to eighty years, while in all catchment basins important works of cultivation were undertaken, no marked change of the kind feared was to be recognised. The observations at Düsseldorf were especially important, partly because they embraced the longest period, partly because taken on the Rhine, which, according to the Vienna data, and also according to the statements in Parliament, ought to have indicated the danger. The careful investigation showed directly the reverse; it proved satisfactorily a progressive sinking of the highest water-level, and at the same time, with some probability, a slight raising of the lowest water-level.

With regard to the different stations investigated, it seemed that the mean water-level of the Rhine, the Mosel, the Weser, the Vistula, the Pregel, and the Memel had remained unchanged during the period considered; for the small, sometimes positive, sometimes negative changes which the methodic treatment exhibited as probable, did not exceed the values of the probable error. This was true also of the observations made at Frankfort, on the Oder, with some probability, while those kept at Neu-Glietzen, on the same stream, permitted a small progressive sinking to be conjectured. For the Elbe, on the contrary, both stations give decisively a sinking of the annual mean water-level; yet it ought not to be unmentioned that at Torgau, for the twenty-seven years from 1819 to 1845, a regular raising might with greater probability be recognised.

The absolute highest water-level of each year on the Rhine, the Mosel, the Weser, the Elbe, the Oder, and the Pregel showed a probable progressive sinking, which for some of these stations was

[1] *Vide* "Ueber Veränderung der Wasserstände in den Preussischen Strömen." Königl. Acad der Wissenschaften zu Berlin, 1880.

Digitized by Google

even certain. For the Memel, and one station on the Vistula, it remained constant, while for the other station on this river, with some probability, it was regularly raised. Mr. Hagen.

Finally, as to the absolute lowest water-level, for the Rhine, with some probability, and for Höxter on the Weser, a progressive raising was satisfactorily exhibited. For all other stations an increasing sinking could be inferred.

If, according to these researches, the water-level of these rivers in the given period had suffered some changes, it ought to be attributed not to the extension of cultivation, which in part had had an opposite influence, but to the regulation of the rivers. This caused the progressive sinking of the highest yearly water-level exhibited, with few exceptions. The regulation had been carried out freely, especially in the interest of the navigation, so that in the shoal parts a deeper waterway was formed; then a stronger current was established, and the discharge of the water was facilitated, both in the part dealt with, and throughout the river. By this yet another important advantage was obtained, bearing on the inquiry. In continuous frost, and also at the breaking up of the ice, when ice-blocks drifted, a deep channel was not easily dammed. The firm cover formed over it, on which new ice-flakes were continually driven, did not so easily take the ground as when a shallow bank reached from shore to shore. The channel did not possess absolute safety, but herein consisted the safest means of preventing a dangerous ice-block. Accordingly, as far as possible, sharp bends and very irregular widths of the channel should be removed. By this the discharge would be facilitated, and at the same time the opportunity taken away for the ice-blocks to accumulate in places, which they always did if they passed from a rapid stream to a wider channel, where the movement almost ceased.

The regulation of the river valley, so far as it was subject to floods, had also been latterly undertaken. It should have, as far as possible, a straight direction and a uniform width. Ordinarily these conditions could only be imperfectly satisfied, but it often succeeded to construct regular passages (*sanfte Uebergange*), and to remove abrupt dykes, detached buildings, and other artificial obstructions, as well as trees and underwood. This care for the unhindered and regular discharge of the water, both in the channel of the stream and in the whole flooded valley, was without doubt the cause that the highest water-level was lower than formerly.

The regulation of the stream had also an important influence on the lowest water-level. So soon as a shallow was replaced by a deeper

Digitized by Google

Mr. Hagen. channel, the water above was somewhat lowered. Still more did this happen if a wide sinuous channel was replaced by a straighter and shorter one. Since the important works of this kind on the Ober-Rhine, between Baden and Rhein-Bayern, came into operation after 1820, there had been a marked lowering of the water-level above. This was the object of the works executed in the previous century on the Alle, a tributary of the Pregel, which was to be made navigable. The countless granite blocks lying in the bed of the river were removed to a prescribed depth. At the beginning of the operations, the navigable depth was obtained over a short distance as desired, but on proceeding the depth diminished to what it was before. The bed was lowered, but the water-surface sank just as much. Such an unfortunate consequence did not arise with large rivers, which never had so great a fall. Nevertheless, foresight was often required even with these, to extend over a greater length the diminution of width, by which a deeper channel was formed and maintained; or if a superfluous depth was obtained, to diminish it by low sills (*Schwellen*), in order that above the regulated section the water-level should remain at the height which navigation and farming required. This motive, which had been hitherto little regarded, was now taken as a basis of projects. If, therefore, according to observations in German rivers, the lowest water-level was found in many cases to have sunk, the reason of it ought to be sought rather in artificial regulation than in diminished discharge.

Mr. de Lagréné. Mr. H. DE LAGRÉNÉ, Engineer-in-Chief of the Third Section of the Seine Navigation, regretted that the Papers did not contain sufficient details of the embankments, locks, dams, &c., to allow of the enunciation of other than general propositions concerning the subject under discussion.

If he rightly understood the two communications, the rivers mentioned were more or less encumbered by shoals, resulting from floods and from the refuse of manufactories, and they had been treated in various ways in the direction of preventing inundations, procuring the reclamation of marsh-land, and improving the navigation, but that for some reason the results were not satisfactory. The following were the principles upon which he should recommend future improvements to be carried out:—First, combined action. One of the reasons why the existing works had not produced all the benefit anticipated was, that they appeared to have been designed and executed on local lines; that was to say, without regard to any general plan, and without the control of a superior authority to care for the interests of the whole valley. It resulted

Digitized by Google

that the works of one section clashed with those of the other parts, that their maintenance was perfunctory, and that large sums had been expended in litigation instead of in river improvement; finally, that certain privileges appertaining to riparian ownership had had to be respected, although known to be hurtful to the regular flow of the waters. Mr. de Lagréné.

Mr. Lagréné did not know whether the English law allowed this capital default to be amended; it appeared evident to him that, for the welfare of such important streams as those under discussion, it was necessary that the conservancy should be a uniform system applicable to the whole valley, and should be under the direction of a superior authority, entrusted not only with the power of sanctioning the proposed works, but also of superintending their execution. The same authority (one for each valley) should have the manufactories under their surveillance, and have power to prevent the abuse of water privileges by the occupiers. The points to be aimed at were: 1. Protection against inundation; 2. Reclamation of marsh-land; 3. Efficient navigation; 4. Sanitation and water-supply of inhabited lands; 5. Use of water for industrial purposes and for irrigation; 6. Fish preservation. Although some of these might conflict with others, the aim should be to satisfy the whole of them as far as might be. He would only refer to the two subjects, floods and navigation, dealt with in the Paper.

Secondly, works for preventing floods. The Authors were right to reject large impounding reservoirs, as, in order to be of use, they would have to be placed low down in the valleys, where the land was generally most valuable, and their construction would be costly. Also, their functions would be exercised at times irregular and far apart, and they would induce serious opposition from the neighbouring inhabitants.

Longitudinal banks, notwithstanding their occasional failure, offered the best preservation against floods, but certain considerations attached to their establishment. For instance, as no absolute knowledge could be obtained of the height of future floods, no ordinary embankment should be considered as offering absolute security, and the riverside owners should understand that bursting of the bank was a contingency to be allowed for, which it would be prudent to meet by some sort of accident assurance. Further, it was advisable not to make the banks unnecessarily long, because the more scope allowed to a flood the less dangerous it became, and consequently the less scour would occur in the river-bed and banks. The embankments should therefore be confined

Digitized by Google

Mr. de Lagréné. to places where floods were prohibitive, and the height of such embankments should be proportioned to the value of the lands protected by them. Thus, in towns, high embankments were advisable, so as to give, as far as possible, absolute protection. For a wide fertile plain a bank should be made of height adapted to the value of the produce and the mode of cultivation. For land of small value and lying fallow, it might possibly be worth while just to diminish the chances of inundation by putting up a low bank; then, as the land became more valuable, or was brought under cultivation, good reason might be found for raising the embankment piecemeal until nearly absolute security was attained.

To sum up, it should be the aim to limit, as far as possible, the parts embanked, and to proportion the height of the banks to the value of the parts protected. The profile would show a certain number of discontinuous embankments, between which the waters would circulate freely, gradually raising the surface of the soil by deposits, sometimes fertile, sometimes inert, and diminishing by dispersion the height and the velocity of the flood.

The Paper relative to the Irwell alluded to various cuts to straighten the channel, and hasten the discharge of floods. Perhaps he had not properly understood the objects of these cuts. They might do to preserve the embanked portions, but it appeared to him that they would be very dangerous if used for discharge instead of the natural bed. They would virtually produce an artificial flood greater than the natural one; further, the greater velocity resulting from the steeper incline would occasion scour, and, sooner or later, deposits.

Thirdly, navigation works. In rivers like those under consideration, namely, of small tidal capacity, and of a character more or less torrential, efficient navigation could only be secured by the provision of locks and dams, unless, indeed, it were preferred to discard the natural bed and to construct a lateral canal, as Brindley had done in the case of the Bridgwater canal. But this solution might be disregarded, as it was not referred to in the Papers. Mr. Jacob's Paper discussed the question whether or no the locks on the Irwell had raised the surface of the floods. The particulars given were not enough to enable an opinion to be formed on this point. It was evident that the influence of such works would depend upon their disposition, of which Mr. de Lagréné knew nothing.

In a general way it might be assumed that a lock combined with a fixed dam exercised an injurious influence on the discharge of floods, and the passage of solid bodies brought down by the current. On the other hand, a lock combined with a movable

Digitized by Google

dam, especially if the lock-gates allowed of its being fully opened, might be taken as quite harmless. Mr. de Lagréné.

Mr. Wheeler's Paper alluded to various modes of training and improving the channels of rivers in their outfalls, but no reference had been made to the system of sluicing. The question of outfalls was otherwise too well understood in England for him to offer any useful remarks on the subject.

Mr. E. MALÉZIEUX would confine himself to a succinct indication of the views held officially in France on the prevention of floods. The natural remedy in cases of overflow was embankment. Banks might be made high enough to be above the range of floods, or they might be so constructed as not to be injured by water flowing over them. Experience proved that so-called unsubmergible embankments finished by giving way, and naturally the results in such cases were much more disastrous than in the case of a natural flood. Except at very great cost, it was impossible to give to unsubmergible banks a solidity proof against all stress. In France, they were no longer adopted, except for the protection of towns and centres of population. Humanity, no less than the importance of the interests involved, prohibited the abandonment to their fate of towns whose foundations, however imprudently originated, reached back far into the night of time. A law of the 28th of May, 1858, enacted that the State should undertake works for the protection of towns from inundation, providing also that "the departments, communes, and owners should contribute to the cost of the works in proportion to their respective interests." Mr. Malézieux.

With such exceptions only submergible embankments were now made in France. The less high they were, the less subject to rupture. Further, they did not entail the grave disadvantage of depriving of fertilizing irrigation the naturally submergible parts of the valleys. The difficulty here principally lay in an economical consideration of local conditions.

In the case of the River Loire, a special disposition had been adopted. It had been decided to place at intervals in the banks masonry overflows, of which the length (say from 400 to 500 yards), and the height were of suitable proportion. The masonry was surmounted by a ridge of vegetable soil grassed, which would be carried away before the water could attack the banks. Immediately below these overflows the land, purchased beforehand, was protected from scour by rough stonework. The sites of the overflows were so chosen that the water should do as little injury as possible to the valley. The Jargeau overflow had just

Digitized by Google

Mr. Malézieux. been finished on this plan, others were about to be built, but no flood sufficiently high to test it had yet occurred.

The problem of the location and height to be given to embankments, would be notably simplified if account had not to be taken of the ancient levees, constructed here and there without method, which could not be made to fit in well with any general scheme. All that could be done in such cases, was to take care that the evil was not exaggerated. The law of May, 1858, enacted that "there should not be established without application previously made to the State, who should have the right to interdict or to modify the works, any bank in the submergible parts of the valleys of the Seine, the Loire, the Rhone, the Garonne, or their affluents hereinafter named." Any infraction of this clause would be punished. The State could even (on payment of an indemnity) shift, modify, or remove any bank which might be proved to be an obstacle to the free passage of water, or sensibly to prevent the range of lands submerged.

About twenty years ago much attention had been directed to another means of preventing, or at least of diminishing the effects of floods. Vast reservoirs were to be made, kept empty during the dry season, in which might be retained the water from heavy rainfalls, so that it might be released progressively and at preconcerted times, in such a way as to prevent the coincidence and the accumulation of the flood water from several rivers of the same basin. It had been found, however, that this plan, very simple in theory, would be difficult and uncertain in practice, and that it might under some circumstances do more harm than good. This was referred to in a paper in the "Annales des Ponts et Chaussées," vol. ii. of 1881, p. 6.[1]

Besides works executed or contemplated for dealing with floods, mention might be made of the system of warnings, as an efficient means in the same direction. Methodical observations of the varying height of a certain number of streams, taken in the upper part of the principal affluents of each basin, and telegraphed to an engineer for collation, enabled him to forecast to the stations below the probable course of the flood about to commence, notably as concerned its duration and extreme height at the most important points of the valley. On receipt of these warnings, which were becoming every day more trustworthy, the movable dams were opened, lower quays cleared, and the riparian occupiers on the

[1] Abstracted in the Minutes of Proceedings Inst. C.E., vol. lxvi., p. 408.

Digitized by Google

alert. By this means important results were obtained at little cost.[1] Mr. Malézieux.

Mr. Malézieux would also refer to the police regulations long existing for the protection of riverain property against inundation. By law 16-20 August, 1791, the Prefect of a Department had "to seek for and indicate the means of procuring a free discharge of the waters, to prevent the lands being submerged by the too great raising of the sluices of mills and other works established on rivers" . . . . As the Prefects are all in that way, under the orders of one special minister, there is no occasion to dread here that conflict of jurisdiction and interests so much deplored in England. This has an advantage naturally resulting from centralised administration. The Prefects may decide, without reference to the Minister, but on the advice or the proposition of the chief engineer, as to the repartition between manufactures and agriculture of the waters of streams not navigable nor floatable, according to the manner prescribed by ancient custom and local usage.

If it were sought not to prevent injury from superfluous water, but to hinder it from reaching the sea without doing useful work, recourse might be had to reservoirs. That of Rochetaillée, described in the "Annales des Ponts et Chaussées," 1866, vol. ii., p. 184, fulfilled two objects. Its lower part, from the bottom to an extreme height of 44 m. 50 c. (146 feet), say a capacity of 1,200,000 cubic metres (264 million gallons), was entirely devoted during the dry season to supplying with water the town of St. Etienne and several factories at Furens. The upper part, 5 m. 50 c. deep, and of 400,000 cubic metres capacity (88 million gallons), served to retain the injurious part of the floods. For this purpose it was kept empty at ordinary times. The Settons reservoir, of a capacity of 23 million cubic metres (5,060 million gallons), sure to be filled every year, served to augment the volume of low water in the Yonne and the Seine above Paris. Other reservoirs lately constructed proved that for alimentation these works retained their utility.

Replanting mountains, of which the use was at one time contested, would contribute powerfully to a regulation of the regimen of rivers, by diminishing inundations, and augmenting the low-water flow. This would yield a double and immense service to agriculture and to industry. Much was to be hoped for in this direction from the special department constituted in France under the Minister of Agriculture.

In regard to public health, a law of the 16th of September, 1807

[1] In a paper in the "Annales des Ponts et Chaussées," vol. i. of 1880, p. 579, was proposed an ingenious mode of notation and of representation of the observations made on the height of rivers.

Digitized by Google

Mr. Malézieux. (Art. 35), enacted that "all measures of health concerning towns and communes will be ordered by the Government, and the costs supported by the communes interested." By reason of this, the Administration could interdict towns from discharging their sewage into rivers below their jurisdiction, without previous purification.

As regarded the preservation of fish, a law of the 15th of April, 1829 (Art. 25), amended by an order of the Court of Cassation of the 27th of January, 1859, had partly provided another of the desiderata indicated in English legislation. This law prohibited discharging into rivers, at least into navigable or floatable rivers, the only cases to which the law applied, the refuse of manufactures hurtful to fish.

Mr. Price. Mr. J. PRICE, being engaged in the Loughs and River Erne, had gone very closely into the question; without anticipating some future description of this work by way of comparison, he would state, that the catchment basin exceeded 1,000,000 acres. The works would extend over a tableland about 70 miles in length, practically level throughout, having in a length of 53 miles a fall during summer of only 2 feet; from this tableland the river would have a fall, along a rocky channel, of 152 feet in a distance of 5 miles to Ballyshannon, where it fell in a cataract into the Atlantic.

The channels were calculated to discharge 0·4 of an inch of rain from the whole catchment basin in twenty-four hours. Such floods, however, would be of short duration, perhaps never longer than two days; lesser floods of 0·25 of an inch would last longer, but from the equalising effect of the lakes acting as reservoirs, the shorter and heavier floods, and longer and more moderate floods, could be dealt with in the same manner and discharged without flooding the margins.

Of the whole 70 miles over which the works extended about 40 were comprised in the lakes. These lakes covered about 40,000 acres. The floods rose 9 feet and flowed over 17,000 acres. The works consisted principally of rock and earth excavation, not much being of an alluvial nature. The navigation would be preserved and much improved, affording 60 miles of water in one level without a lock. All previous plans divided the navigation into levels. Such another inland level did not exist in the United Kingdom. At the outlet there would be four large sluices each with 29 feet clear waterway, and 15 feet head; they were to be constructed on the system of Mr. F. G. M. Stoney's roller-sluices worked by turbine. The outlet would be connected by telegraph with the distant portions of the upper lake, and would automatically register every rise, enabling the attendant to open the sluices, and, by lowering the adjoining lake, to anticipate all floods by at

Digitized by Google

least two days. The minimum channels during flood would have 1 square foot of sectional area for every 390 to 423 acres of catchment basin. There would be no embankment; nearly all the stuff would be dredged and deposited in deep water from hopper barges. Mr. Price.

Mr. Price did not approve of keeping the river channels small to avoid weeds. Weeding was a matter easily accomplished by a revolving and self-cleaning steam-rake; he preferred having the channels deep, and he would recommend, when the bottom was soft and to be excavated by dredging, a channel of a depth in the centre of about one-seventeenth of the surface width, and of the form of a hyperbola, of which the natural slope of the soil would be the asymptote; this was a natural form preferable to the trapezoidal form generally adopted.

He would lay down the following general principles:—

1. That it was possible to combine drainage, mill-power and navigation, by the use of sluices instead of fixed weirs, aided by a telegraph to forewarn of coming floods.

2. Where there were no lakes on the course of the river, certain suitable lands should be enclosed by low embankments so that the greater floods of winter might lie on them for a short time, generally to their great benefit; but that the channels should be excavated large enough to run off all summer and autumn floods without overflowing these lands—such shallow lakes or washes giving, as it were, time for the sluices to work effectively. Time was an important element in connection with the floods and the sluices; great floods being generally of short duration, and in most cases before the sluices became insufficient, as they might in some very great long-continued and exceptional flood, the downpour would have ceased.

3. That the works should be carried out and maintained by dredging, and that the channels should be deep in the centre and generally of the hyperbolic form.

Much of the difficulty of devising drainage plans arose from the want of previous observations of rainfall, floods, discharges, and the levels of the water at various places during floods, all of which required a long series of years. In the case of Lough Erne, he had been greatly assisted by the promoter, Mr. J. G. V. Porter, of Belleisle, Co. Fermanagh, who furnished observations of the levels of the lakes taken daily for many years. Mr. Porter had been indefatigable for above sixteen years in bringing about this work of drainage and navigation; many plans were previously worked out by eminent engineers, notably Mr. James Barton, M. Inst. C.E.,

Digitized by Google

Mr. Price. and Mr. Lynam; though indebted to previous plans for valuable data, the present plan was diverse in many respects. Mr. Hawksley, Past-President Inst. C.E., had been appointed the Inspector by the Irish Board of Works, to report on the plans; these met with his approval, and his further suggestions had been adopted as far as possible.

To this work £15,000 had been contributed by the Government, and £15,000 by the surrounding counties for the improvement and preservation of the navigation, which sums together came to one-fourth of the whole cost, the remaining three-fourths being lent by the Treasury, to be repaid in thirty-five years by a rate on the occupiers of the flooded lands; the rate would be about 5*s.* 4*d.* per acre. The improved value which had been estimated at 6*s.* 4*d.* per acre, did not, however, fully represent the gain; it was the value of the improvement in ordinary years; but every few years autumn floods take place, causing immense loss. For instance, the summer and autumn of 1879 floods caused a loss estimated at £40,000.

Mr. Reid. Mr. R. C. REID desired to record some particulars of the flood, on the 9th of March, 1881, in the district of the River Tweed, said to have been one of the highest on record, on which occasion several bridges of the North British Railway were so much damaged that traffic had to be suspended for several days. The River Tweed drained the Silurian uplands of the South of Scotland, the height of some of the hills in its catchment basin being 2,500 feet above the sea. The flood in question took place immediately after the break-up of the frost, when the hills were covered with snow several feet deep. A thaw set in accompanied by rain, and thus from the melting of the snow made the flood more intense. The position selected for measuring the extent of the flood, was at Abbotsford Ferry, about 1 mile below the point where the Tweed was joined by the Ettrick. The drainage area of these two rivers at the point was 362,726 acres, or about 565 square miles; and from measurements taken after the flood had subsided it was found that the river had risen 12 feet above its ordinary level, and that its maximum discharge could not have been less than 1,856,928 cubic feet per minute, or at the rate of about 5 cubic feet per minute from each acre.

Similar observations were made on the River Gala, which joined the Tweed about 1 mile below Abbotsford Ferry. This river drained a district similar to that of the Tweed, but having a shorter run the flood was more intense. At the town of Galashiels the Gala had a drainage area of 47,334 acres, or about 75 square

Digitized by Google

miles, and when the flood reached its maximum the discharge there was 410,764 cubic feet per minute, or fully 8½ cubic feet per minute per acre. Mr. Reid.

The valleys in which these two rivers ran were comparatively narrow, so that the area of land damaged by actual flooding was limited, but the destruction of the river banks and of mills and other properties along side the river was unprecedented.

Mr. J. SMYTH, Jun., concurred in the opinion that, as a rule, the management of each watershed area ought to be under the control of one general Board. He had known great evils to arise from contending interests. Of course, the various river systems would require different treatment, and the existing interests must be interfered with as little as possible. A general Conservancy Board might include all interests, such as landholders, farmers, millowners, sanitary authorities, towns, and villages, water supply, fisheries, and navigation. As to the incidence of taxation, it was reasonable that both lowlands, midlands, and uplands should contribute in proportion to the benefits received. Mr. Smyth.

His experience was chiefly concerned with the Upper Bann river in the North of Ireland, from living on its banks, and from having been connected for many years with the Bann Reservoir Company. The River Bann rose in the Mourne mountains, at an elevation of 2,198 feet above the sea, and flowed in a northerly direction through Lough Neagh, the largest lake in Ireland, into the North Atlantic Ocean, at Coleraine. It was 85 miles in length, and its drainage area was 2,345 square miles, including the surface of Lough Neagh. It was the third largest river in Ireland. Most of the branches of the Bann also rose at a high elevation, and had a rapid descent towards Lough Neagh, a circumstance which had been taken advantage of by the inhabitants on the banks, to build mills driven by water-wheels, and which contributed in no small degree to the establishment of the linen trade in the North of Ireland. As business increased, it was found that the supply of water to the mills in seasons of drought was insufficient. In the year 1835, therefore, the Bann Reservoir Company was formed to provide a better and more regular supply of water for the mills. The Company appointed the late Sir William Fairbairn, M. Inst. C.E., as chief engineer, and Mr. J. F. Bateman, Past-President Inst. C.E., as assistant. The construction of two impounding reservoirs, Lough Island Reavy and Deer's Meadow, and one auxiliary reservoir, Corbet Lough, was recommended. Lough Island Reavy reservoir was the first constructed according to the plans, and under the superintendence of Mr. Bateman, and was finished

Digitized by Google

Mr. Smyth. in the latter part of the year 1839. The Corbet reservoir was also constructed, but not to the full extent contemplated, as the embankments were made to impound only 11 feet 3 inches, instead of 18 feet depth of water; it was not completed until 1847. Lough Island Reavy reservoir was situated in a narrow valley on the north-east flank of the Mourne mountains, and received three-fourths of its supply of water through a conduit from the Muddock river, a tributary of the Bann, and one-fourth from the Moneyscalp river, which did not belong to the Bann drainage area, but flowed into the Irish Sea near Newcastle. The water was impounded to a depth of 35 feet above the old lake, and was 430 feet above sea-level. The area of the reservoir, when full, was 250 statute acres, and the capacity 270 million cubic feet.[1] Difficulties had been met with in the working of the reservoir, which a better Act of Parliament, or the regulation of the river by a Conservancy Board, might have prevented. The necessary supply of water from the reservoir was conveyed to the Bann for 6 miles down the Muddock river, which was sluggish and winding for the last 3 miles, before it joined the Bann, and its banks were so low as to be flooded after heavy rain, not only by the surplus waters of the Muddock, but also by those of the Bann. These floodings and minor ones caused by the overflow over some of the lands, when the water was being sent down to supply the Bann, owing to obstruction from weeds and the silting up of the channel, had been the source of actions against the Reservoir Company by the farmers holding these lands. This difficulty arose from a dispute as to whether the Company or the riparian proprietors should cleanse the stream. In the end, it was decided that the responsibility lay with the Reservoir Company, who therefore made an arrangement with the farmers for the removal of the cleansings, and cleaned out the Muddock river in the summer of 1878. The proper supply for the mills could be now secured without the channel overflowing. The directors of the Company had also erected a gauge-weir board across the channel, at a short distance below the discharge-pipes, the better to regulate the supply of water sent down. From the junction of the Muddock river with the Bann to Errin's weir, where the surplus water was caught by the feeder leading to the Corbet reservoir, a distance of 8½ miles; there were about 30 feet of unoccupied and 7¼ feet of occupied fall on the River Bann. At this weir, daily measurement was made of the quantity of water

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), p. 168; and Transactions of the Inst. C.E. of Ireland, vol. ix., p. 51.

Digitized by Google

Mr. Smyth.

coming down the river, and the amount of water to be supplemented by the reservoirs was thereby regulated. The area of the Corbet reservoir was about 70 acres, when the water was at top level, or 11½ feet above the discharge outlet. The cost of these works had been about £30,000; the income was derived from a rate of £10 per annum per foot of fall, levied on linen bleachers, manufacturers, and spinners, and £5 on corn and flax-scutch millers. The fall from the outlet of Lough Island Reavy to the tail-water of the last mill, was 350 feet, of which, however, at present, only 180 feet could be rated. Lough Island Reavy reservoir had been in operation forty-one years, and had well borne out Sir William Fairbairn's anticipations of its utility in supplying water to the mills. In his calculations he assumed the yearly rainfall at Lough Island Reavy to be 36 inches, which at that time was considered the average for Ireland. Allowing one-sixth for absorption and evaporation, he concluded there would be sufficient water to fill the reservoir one and a quarter times on an average in the year. Subsequent observations within the drainage area of the upper Bann river, showed an average annual rainfall at Banbridge of 31 inches, at Lough Island Reavy of 45 inches, and at the Butter mountains of 83 inches. He assumed, therefore, the average rainfall in the drainage area of Lough Island Reavy, which was 5 square miles, as 60 inches, and consequently the year's rainfall as 697 million cubic feet. A fall of 30 inches at the reservoir, equal to 40 inches over the whole area, was necessary to fill the reservoir from the beginning of October to the beginning of April, when it was generally full. As a rainfall of 23 inches over the area filled the reservoir, there resulted a loss of two-fifths by absorption and evaporation; but as the evaporation from the surface of the lake must be large, and there was some loss at the intake from a portion of the water occasionally getting over the weir, two-thirds might probably be discharged into the lake. It was, therefore, fortunate that Sir William Fairbairn had estimated the rainfall so low, as he did not allow enough for waste. Lough Island Reavy had supplied in thirty-four years, an average additional amount of one-half the summer standard discharge for 3,371 days, or, yearly average of 99·1 days of twenty-four hours, and had been empty 337 days, or an average of 9·9 days. As the Corbet reservoir commanded the surplus water of 80 square miles of drainage, it was filled several times in the year, and supplied about half as much water as Lough Island Reavy. Add this to the Lough Island Reavy, and there was a total supply of 150 days.

Digitized by Google

Mr. Smyth. From calculations made of the amount of water flowing down the river at Ennis weir, he found there was an average of about 5½ billion cubic feet in the year. The normal flow kept up by the reservoirs would amount on the whole to about 2 billion cubic feet; and, as one-half the supply was not made available, there would be an advantage in constructing more reservoirs, not only at the sources of the River Bann and its branches, such as the Rocky and Leitrim rivers, but at other sites along the course of the river, where land was not very valuable to impound the surplus water, as had been done to a limited extent in the case of the Corbet reservoir. About five-eighths or three-fourths of the annual flow might thus be conserved, and the water-power might not only be made more valuable, but enough water might be provided for a sanitary supply to the towns on the banks of the river. The most important towns were Banbridge with a population of six thousand inhabitants and Portadown with eight thousand. The drainage area of the Upper Bann was only 134 square miles, or one-nineteenth of the Bann or Lough Neagh drainage system. The largest tributary was the Blackwater river, with a drainage area of 626 square miles, next the Main river, 277 square miles, then the Balinderry rivers, 166 square miles, and the Upper Bann and the Moyola, 129 square miles. It was singular that reservoirs had not been constructed on any of these but the Bann. There were very important towns on and near some of these rivers, and now that electric lighting was being so much adopted, a portion of the water-power thus acquired could be used to drive the electric machines. These reservoirs, too, would have a good effect in diminishing the floods from which the town of Portadown and the extensive lowlands in the vicinity of Lough Neagh suffered. So much had floods been felt in past years that efforts had been made by increasing the discharging power of the Lower Bann river (the only outlet to the sea for the entire Lough Neagh drainage area) to lower the surface of the lake, and thus free the lands in its vicinity. Mr. R. Manning, M. Inst. C.E., chief engineer to the Board of Works, Ireland, and Mr. W. J. O'Neill, engineer to the Lough Neagh Drainage Trustees, had furnished him with their respective reports on this subject. Mr. Manning's report was dated June 8th, 1877, and he quoted some portions of it: he said, "Lough Neagh, which is nearly 100,000 acres in extent, receives waters flowing from 1,865 square miles of country. The quantity of land flooded by the rise of the lake and river was nearly 30,000 acres, 21,000 of which are situated above the outlet

Digitized by Google

at Toome. In the month of December, 1845, the late Mr. McMahon, C.E., submitted to the Board (of Drainage Trustees) a report on the proposed drainage of the lands, and the establishment of a navigation from the sea to Lough Neagh." . . . "The works were commenced in 1847, and were completed in 1858, with little if any deviation from the original design." . . . "On the 10th of March, 1859, Mr. James Barton examined the state of the navigation works between Toome and Coleraine, and concluded his report by expressing his opinion that the navigation works were a credit to the country as a public work." "I may be permitted (after my recent inspection) to state my full concurrence in this opinion, and to add that as the excavation necessary for navigation formed a part of that required for drainage also, the efficient execution of the one involves to a great extent that of the other. Speaking generally, it may be said, with the exception of the present year, when flooding occurred in the month of April, the lands above Toome have been completely free from floods for seven months in every year, from April to October, both inclusive. It appears, then, that, considered as an agricultural drainage, the works, even up to the present time (certainly at least with respect to all grass lands), have been successful; they were quite so up to the time of their completion, and with little exception for five or six years afterwards. But it is this very success that has caused the effects of the floods of last winter to be so severely felt by the occupiers. Low lands have been turned to tillage, and houses built upon them. This is especially the case in the neighbourhood of Portadown, where factories and streets of artizan's dwellings have been built on ground which, previous to the drainage, must have been under water for months together." As to the causes of the flooding Mr. Manning said, "In the present state of the district, 7 inches of rain falling in two winter months (where there is little or no evaporation) will produce a discharge which will partially flood the lands. The great flood of the 2nd and 3rd of February, 1877, was preceded by a fall of 12·30 inches in the previous two months; in addition to which the rainfall at Hilltown, near the head of the Upper Bann river, for the year 1876 was 66 inches, the average being about 48 inches, and the maximum in previous years being probably not more than 55 inches, the large rainfall would sufficiently account for the great and constant floods which occurred from December to April last, but the flooding during the previous twelve years (1864 to 1876) has in my opinion been mainly caused by the insufficient area of the channel from Toome to Portna." . . . "All the circumstances stated point, therefore,

Mr. Smyth.

Digitized by Google

Mr. Smyth. distinctly to the fact that the channel at present is much less efficient than at the completion of the works, and there can be little if any doubt that the increased height of the water in recent years has arisen, mainly if not entirely, from this cause."

In a report dated the 4th of December, 1877, Mr. W. J. O'Neill showed from measurements taken at the various shoals or fords, how far they were insufficient in sectional area to discharge the 400,000 cubic feet per minute, contemplated by Mr. MacMahon as necessary to keep the maximum flood-level of Lough Neagh at a height of 2 feet above the present or improved summer level, and in reference to which the works were designed and carried out. Mr. O'Neill had supplied him with additional particulars. He said the former summer level of Lough Neagh, before the improvements were carried out, was 48 feet above the old ordnance or trigonometrical datum (which was about 5·60 feet above the datum of the contours or bench mark levels). The present summer level was 46 feet above old datum. In winter the flood reached 49 feet, and sometimes a few inches higher. In 1856 it reached from 2 to 6 inches above 50 feet, and one winter 52 feet. The cost of the Lough Neagh combined drainage and navigation works had been, for the former £158,423 3*s.* 6*d.*, for the latter £104,574 10*s.* 4*d.* The first amount had been reduced by a Government grant and moneys chargeable to counties for bridges to £110,000; the second had been reduced by a Government grant to £37,137 10*s.* The first had been repaid in about twenty-two years by a tax on 29,597 acres 2 roods 32 poles of lands drained and improved; the second by 740 townlands in county Londonderry and 750 in county Antrim, or 547,807 acres 3 roods 27 poles, of the annual value of £429,656 10*s.* Mr. O'Neill further said there were many complaints about the drainage in wet years, but he did not consider them well founded, although he believed the district could pay for further improvements in the Lower Bann river.

Several other plans had been mooted for diminishing these floods. Colonel Campbell, R.E., thought relief might be given by making a cut deep enough to take the surplus waters to Newry *vid* Scarvagh, the summit of the Newry and Lough Neagh canal. The late Mr. Alexander Nimmo, M. Inst. C.E., when consulted upon the supply of water to the Newry navigation, reported, "The summit level was 21 feet above the lake, 3 miles long, soil mostly soft, much of it bog, and of little relative value. It would be a matter of great expense and difficulty to cut it through, and to bring the surface level of Lough Neagh through the valley towards Newry." Such a scheme would of course now be hopeless; it could

Digitized by Google

scarcely be accomplished at a cost of £500,000, and at that time (1822) it was opposed by some of the landholders. A canal was once partly made from the River Bann at Banbridge to join the Newry navigation at Scarvagh; it had to be abandoned, however, being opposed by the millowners on the Bann on account of the loss of water it would have entailed. Mr. Smyth.

Mr. HOWARD UNWIN remarked that in dealing with the question of River Conservancy in England it might be useful to ascertain what was done in other countries, and it was possible to learn something from the manner in which the Government was now dealing with the rivers in India, more especially with the rivers in Bengal and Orissa. The lower reaches of these rivers were, for the most part, embanked, and the duties of maintenance and supervision of over 2,000 miles of embankment devolved upon the officers of the irrigation department. This was exclusive of a still greater length of smaller embankments on the subsidiary rivers, which were kept up by the landlords. An idea of the importance of this charge might be formed from the fact that a single breach in the embankment near Midnapoor caused the inundation of 35 square miles of country, and the total destruction of the crops. The early records of the country did not give much information on the subject of the maintenance of the embankments. It was clear, however, that from time immemorial the cost of keeping them up was included in the rent payable by the landlord, and that the repairs were executed by them solely, and apparently without any interference on the part of the Government. At the close of each year a deduction was made from the rent on account of the repairs executed during the year. This was formerly the practice in Orissa; but when the English Government took the province, in 1803, the control and repair of the most important embankments were taken in hand by the Government, but at the landlord's expense. The increased cost of Government supervision led to petitions being made by the landlords, that the repairs might be again entrusted to them, and a deduction made from their rents, as was the practice under the Mahrattas. This request was not complied with, and as early as 1809 a committee of embankment was constituted, composed of the principal local officers, who submitted estimates for repairs to the Government for sanction. Various changes have from time to time been made in the *personnel* of the committee until the establishment of the Public Works Department; but the principle was always maintained that the responsibility for the maintenance rested in the Government. In Burdwan, and other districts of Bengal, much the same practice Mr. Unwin.

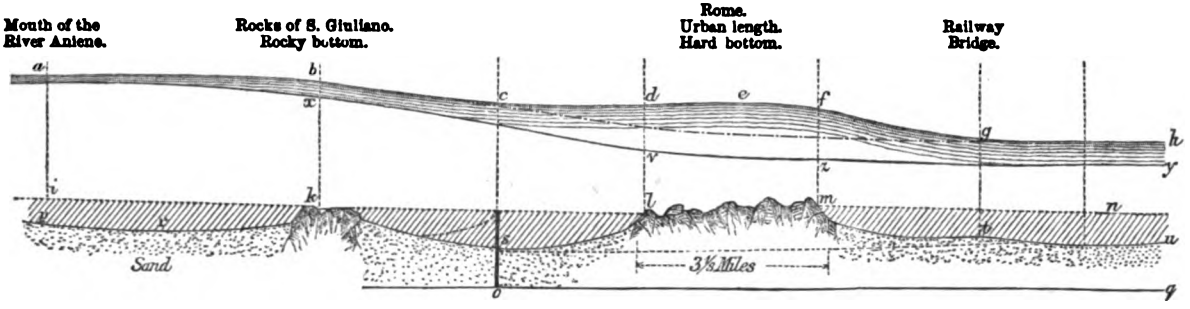
Digitized by Google

Mr. Unwin. was observed. In 1783 the Rajah of Burdwan was allowed a sum of 60,000 rupees for the work, but after some years of neglect the Government, in 1809, resumed their management, and had retained it ever since. In the correspondence of 1803 the Committee charged with maintenance of embankments reported to the Government, respecting an estate under them, that the question is "not what was formerly allowed, but what is desirable and expedient now to be allowed, and we do not consider Government to be pledged to keep up embankments if such embankments shall not conduce to the general prosperity at large." This principle had been embodied in the various Acts passed by the Bengal Council, from time to time, in reference to river embankments. The people, both owners and occupiers, recognised without question the right and wisdom of Government control over all embanked rivers. In more recent years provision had been made in these Acts for carrying out works of improvement; plans and estimates were prepared, objections were heard and disposed of, and the works were fairly paid for on completion by the various estates, in proportion to the benefits derived. It might be argued that the difference of land tenure between England and India made it impossible to apply similar remedies, but the broad fact remained that the good of the majority was the one thing needful, and it could not be left to the caprice of individual proprietors, but must be dealt with by a central authority, acting under the orders of a strong independent Government.

Mr. Vescovali. Mr. ANGELO VESCOVALI forwarded copies of his publications upon the River Tiber, and gave a brief statement in regard to the present position of the question of the Tiber. To form a judgment upon the question a knowledge was requisite of the facts and of the causes which produced them, of the former of which Fig. 4 furnished an accurate idea. This showed the relation between the configuration of the flood-water surface and the nature of the bottom between the mouth of the Aniene and the railway bridge. The floods of the Tiber in the neighbourhood of Rome took the form of the line *a b c d e f g h;* this line exactly corresponded with the condition of the bed of the Tiber, which was composed for the most part of shifting sand, readily transported in time of flood, while in certain parts the bed resisted erosion, either from being formed of tufaceous rock, or from being encumbered with large masses of ruins as where it traversed Rome. Thus it happened that there was in *a b* a heading-up of water due to the immovable bottom *k*, the rocks of S. Giuliano, then a rapid *b e* caused by the scouring of the bottom *k s l* of the tract

Digitized by Google

FIG. 4.



a b c d e f g h	surface of floods.
a b	heading up due to the elevation at *b* from the hard bottom *k*.
b c	rapid upon the bottom which it scoured.
c d	heading up due to the elevation at *d* from the hard bottom *l*.
d e f	swelling due to hard bottom *l m*; bridges and in the city.
f g	rapid upon the bottom which it scoured.
g h	natural fall of the flood.

If the hard bottom *l m* were reduced so that the bottom might take the form *s t*, to the swelling *c d e f g* would succeed the line *c g*. If then the bed were reduced from *s u* to *o q* and regulated by the weir *s o*, the surface of the water would become *a x v z y*.

d v	lowering of the surface of the water due to the weir *s*.
i k l m n	low water.
p r k; k s l; l m; m t u	bottom of flood.

Digitized by Google

Mr. Vescovali. between the rocks of S. Giuliano and the city. Then followed a heading-up *e d* due to the immovable bottom *l m*, immense ruins stretching across the bed, particularly under the bridges, with a great bank of water *d e* in Rome itself; whence came the rapid *f g* as the river passed out of the city, and finally the natural fall *g h* to the sea. The cleansing of the bed of the Tiber through Rome was therefore a most important matter; for, if excavated to a sufficient depth, about 10 feet below zero of the fluviometer at Ripetta, or 6 feet 8 inches below mean sea-level, it would have the effect of making the bottom subject to scouring action, where it was not so at present, and of increasing the waterways of the bridges, which were now greatly reduced by the masses of ruins which lay under them like weirs.[1] The execution of this work would certainly reduce the height of the floods in Rome by at least 5 feet. By straightening the course of the Tiber between Rome and the sea other 5 feet would be gained, and in this way the bed of the Tiber at Rome would be permanently lowered from 10 to 13 feet; the same result would be obtained if, instead of straightening the course, the canalization of the river between Rome and the sea were executed as proposed by his colleague, the engineer Cesarini. Were all these works carried out, the floods at Rome would assume the form *x v z y* instead of *c d f g*, and the amount of lowering *d v* would not be less than 10 feet.[2] Parliament having assigned the sum of £2,400,000 for the systematization of the Tiber, £1,200,000 having been charged to the municipality of Rome, he, as engineer to the municipality, designed the works so as to spend about £1,600,000 upon those within the city, and about £800,000 upon those between Rome and the sea.

In his design he excluded great retaining walls along the embankments as too costly and difficult of construction, and proposed banks at an angle of 45°, with handsome stone revetments.[3] The bed of the Tiber in Rome, and thence to the sea, consisted of fine loose sand down to about 65 feet below low water; and it was only at this depth that a small amount of clay was mixed with the sand; in certain rare instances argillaceous ground having some solidity was found at from 30 to 33 feet below low water. The foundations for walls more than 40 feet high above

---

[1] *Vide* "Studii Idrometrici sul Fiume Tevere," pp. 25 to 29; Minutes of Proceedings Inst. C.E., vol. xliii., p. 356; and "Ancora della Sistemazione del Tevere e specialmente della Conservazione degli Antichi Ponti." Minutes of Proceedings Inst. C.E., vol. lix., p. 384.

[2] *Vide* "Le inondazione sotterranee di Roma," pp. 19 to 22, and 23 to 36.

[3] *Vide* Plate 2 of the Appendix, agli "Studii Idrometrici sul Fiume Tevere."

Digitized by Google

low water would therefore be very costly if made sufficiently solid. For this reason he excluded walls and proposed slopes; the difference in cost between the two systems would be at least £960,000, being £1,450,000 for the walls, and £485,000 for slopes; the difference in the time required for the execution of the works would be even greater than this proportion. Unfortunately, with the idea of making a grander work, and not believing that the expense and difficulty would be so great for constructing walls along the banks of the Tiber, 6¼ miles in length between the two banks, the Government had ordered walls. It had already been shown, in executing a few lengths, that the foundations could not be executed conveniently by ordinary means, and therefore pneumatic caissons were now being tried; this system would succeed, but the expense would be greater. The whole of the £2,400,000 would be expended entirely upon embankment walls, and there would remain nothing, or very little, for constructing the other necessary portions of the system, among which were the great collecting sewers for rendering the drainage of the city independent of the Tiber, which would cost at least £480,000. Parliament had recently recommended the Minister of Public Works to change the system, as would be seen from the Acts of Parliament accompanying the communication; but the Minister and the Council of Public Works were not disposed to adopt the recommendation. This bad direction to the works of the Tiber was unfortunate, for after an immense outlay the only outcome would be two handsome streets, one on each side of the Tiber; without affording greater health to the city, and security for the navigation of the river down to the sea might have been obtained at even less expense by following the idea of the hydraulic regulation of the Tiber with slopes. The lowering of the floods, therefore, by rectification or canalization, could not be obtained even with the addition of £800,000 to the expense decreed by Parliament, because, by lowering the bed of the Tiber 10 or 13 feet after having constructed the great embankment walls upon sand at a depth of only 16 feet below low-water level, almost certain risk would be run of causing them to fall.

Mr. Vescovali.

Mr. Lionel B. Wells remarked that the wet seasons of late years, and other causes tending to depress the landed interest, had given an impetus to the movement aiming at the better regulation of rivers. Undoubtedly much might be done to lessen the damage from time to time incurred by the flooding of low-lying land. But having acknowledged that an evil did exist, too much must not be attributed to artificial, and too little to those natural, causes which

Mr. Wells.

Digitized by Google

Mr. Wells. it would be idle to attempt to control, either being beyond control, or only to be regulated by an unwarrantable expenditure; for, as Mr. Jacob aptly remarked, flood had evidently prevailed from prehistoric times.

The Bill passed by the House of Lords last session and considered by a Select Committee of the House of Commons, was doubtless applicable to many rivers; but there were some, and by no means the least important, whose interest seemed to be jeopardised by the measure. All rivers and estuaries, whether duly conserved by existing authorities, left in a state of nature, or having been brought into an artificial state, were neglected and in a worse condition than if nature had been undisturbed, by the simple process of an application to the Local Government Board, and a report in favour of the measure by their inspector, followed by a provisional order, were to be placed under an authority, which would have the control, in the first instance, of the waters of the river. The following were clauses Nos. 3 and 4 of the proposed Bill:—"3. Any twenty or more owners, or any twenty or more owners and occupiers, of whom one half at least shall be owners, of land of a rateable value in the aggregate of not less than two thousand pounds, and situate in any river basin or contiguous river basins; also any sanitary or conservancy authority having jurisdiction within any part of a river basin or contiguous river basins, may apply to the Local Government Board by petition, praying that such basin or basins, or any part or parts thereof, may be constituted a conservancy district, and that a conservancy board may be established therein, having power to execute all such works as may be required for the prevention of floods in such district, and for carrying into effect the purposes of this Act. 4. On the receipt of the petition the Local Government Board may, if they think a sufficient *primâ facie* case has been made out, and after requiring, if they think fit, security to be given for any costs which may be incurred by the Local Government Board in relation to any local inquiry directed under this section, direct a local inquiry to be made by an inspector, as to the expediency of constituting the proposed district, and as to the limits to be assigned to such district, and as to such further incidental matters as the Board may think fit; and in particular the inspector shall inquire what lands ought to be described as lowlands, midlands, and uplands, for the purposes of this Act, and what works, if any, have been executed for the protection of any such lowlands or midlands from floods, and in what proportion such lowlands, midlands, and uplands, ought respectively to contribute to the expenses of the

Digitized by Google

conservancy board, or some of them." These, he thought, fairly illustrated the line in which action was likely to be taken; and in the Bill, as also in the formation of the Committee to whom it was referred by the House of Commons, the interests of navigation authorities seemed to have been overlooked. In the first part of the Bill, relating to the constitution of the conservancy district, no reference was made to any navigation authority in the instructions to the inspectors, but the proportion of owners and occupiers to be elected, the rating of districts, and the formation of what was really a drainage authority, was arranged for, and from this procedure the only exemptions were in favour of the Conservators of the Thames, the Lea, and some of the larger estuaries. It was difficult, and in most cases impossible, to prove the former state of a river which had been rendered navigable. Take, for example, the Weaver; the lower portion had much less fall than the upper, the banks were low, and the valley necessarily liable to floods. The original Act for making the river navigable was obtained in 1721. Old plans showed the windings of the stream, and it was with difficulty that a navigable draught of 4 feet 6 inches was obtained. Weirs had been built and the water raised, but at the same time the river had been straightened, widened, and deepened to 10 feet throughout the navigable portion, 20 miles from its junction with the Mersey, and by means of side sluices and movable weir-caps, floods were discharged much more rapidly than the original river could have discharged them. Still floods occurred from time to time, though less frequently than in neighbouring valleys, and sufferers could show the damage to their property, in many cases called into existence and augmented in value by the navigation, and this loss was much more likely to gain attention than evidence of what might have been under previously existing and willingly forgotten circumstances, for there seemed to be a general impression that the interests of drainage and navigation were antagonistic, and although no doubt it often so happened, still it was not necessarily the case. The improvements in the Weaver, below the town of Northwich, during the last twenty years, by the removal of certain weirs and enlarging the capacity of others, as well as by increasing the sluicing power, had reduced the flood-level from 10 and 12 feet above the gauge at Northwich to about 8 feet above that level. The highest flood of which he could obtain evidence took place in 1852, and during the last nine years no flood had risen above 7 feet 9 inches. Mr. Wells.

Still it seemed probable that, under the proposed Bill, a new authority would be created which would have power to interfere

Digitized by Google

Mr. Wells. with the working of the navigation, and on which the trustees of the navigation, as trustees, would have no representation; and they might find the powers granted to them by various Acts of Parliament, which had passed the ordeal of Committees of both Houses, superseded by a provisional order of the Local Government Board, granted on the report of their inspector. This appeared a too rough and ready a way of disposing of powers granted by Parliament itself, and he thought that while the Bill fostered by the Local Government Board should give facilities for the improvement of the drainage of the country where necessary, the Board of Trade should see that the inland navigations which had so generally suffered in competition with railways, but were nevertheless useful auxiliaries and afforded cheap means of transit, should not be still further hampered, and that the Inspectors of the Local Government Board should be directed by the Bill to see that the interests of navigation, as well as of riparian owners, were respected, and that the exceptions to the Bill should be extended to all important tidal and inland navigations.

Mr. White. Mr. F. T. WHITE remarked that the principal source of the River Witham was in South Witham pasture, from which point to Lincoln he understood the fall to be about 56 feet. From Lincoln to deep water at Clayhole the fall was stated, in the Witham drainage reports, to be 32 feet 8 inches, giving a fall of about 1 foot per mile throughout the entire course of the river. A depth of 5 feet of water was maintained for navigable purposes by holding up the water at the Grand Sluice, Boston, to the height of 9 feet. The local authorities had concurred in a measure "Act 1880," for the general improvement of the Witham outfall, below the Grand Sluice; with provision towards the joining of the Welland also in this improvement, when the funds could be raised. A further measure, Act 1881, had been also adopted for enlarging the Grand Sluice, and for widening and deepening the river Witham above.

---

13 December, 1881.

JAMES ABERNETHY, F.R.S.E., President, in the Chair.

The discussion upon the Papers "On the Conservancy of Rivers," by Mr. Wheeler and Mr. Jacob occupied the evening.

Digitized by Google

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 1782.*)

"The Weights of Framed Girders and Roofs."

By Joseph Haywood Watson Buck, M. Inst. C.E.

The attention of the Author having been lately directed to various formulæ for obtaining the approximate weight of a girder or roof principal, he now proposes first to ascertain the different limiting spans deduced therefrom, taking the same type in each case as the best means of comparison, and afterwards to suggest the application of general rules, which, he believes, would prove of great service in designing structures of this character, especially in saving time, while ensuring results as accurate as those obtained by the more laborious processes in general use.

With this view he will first observe that the weight of any bridging structure of which the weight is equally distributed, and which carries a fixed distributed load, is given by the following series:—

Let W = the external load.

and W Q = the weight of a girder of the proposed type, of the strength required to carry W, but not its own weight in addition.

Then $W \times (Q + Q^2 + Q^3$ &c., *ad infinitum*) = the weight of such a girder of the strength required to carry W and its own weight in addition.

But the sum of this series = $\frac{Q}{1 - Q}$.

Therefore $\frac{W Q}{1 - Q}$ = the total weight of the girder.

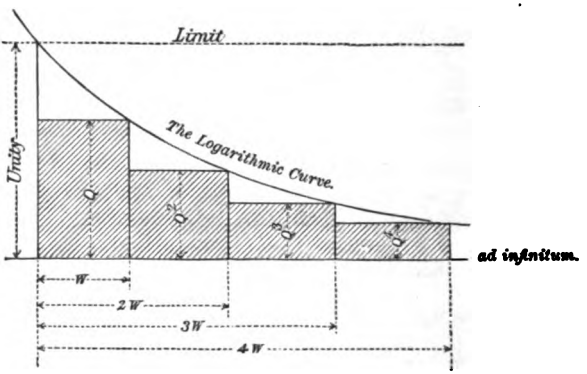
Or, if $W Q = a$,

then $\frac{W a}{W - a}$ = the total weight of the girder.

And the limiting span is reached when Q = 1, *i.e.*, when $a = W$,

Digitized by Google

the sum of the series being then infinity, expressed graphically thus:—



the shaded portion of the diagram representing the weight of the structure.

In a Paper on the reconstruction of the Malahide Viaduct,[1] Mr. W. Anderson, M. Inst. C.E., furnishes the following rule for roughly estimating the weight of a lattice girder of uniform strength, deduced from the distribution of the material in the girders used in that structure, which are of 52 feet span, the strain per square inch of the gross section of the booms being 4 tons, and the depth $\frac{1}{12 \cdot 8}$ of the span.

$$\left.\begin{matrix}\text{Weight in lbs. per lineal foot} \\ \text{of girder}\end{matrix}\right\} = \left\{\begin{matrix}\text{Three times the distributed} \\ \text{load in tons.}\end{matrix}\right.$$

Let W = the external load,
and L = the span.
Reducing to tons,

$$\frac{3\,W\,L}{2{,}240} = \frac{W\,L}{747} = \text{the weight of the girder in tons.}$$

This estimate does not include the weight of the girder itself, but corresponds to *a* in the previous formula. Completing the series and reducing $\frac{W\,L}{747 - L}$ = the total weight of the girder, and the limiting span is therefore 747 feet.

---

[1] *Vide* Transactions of the Institution of Civil Engineers of Ireland, vol. vii., p. 44.

Digitized by Google

Professor Unwin, M. Inst. C.E., in his work "Iron Bridges and Roofs," gives the formula,[1]

$$\frac{W L r}{C s - L r} = \text{the weight of the girder,}$$

C being a coefficient depending on the description of girder, r the ratio of depth to span, and s the strain in tons per square inch of the gross section of the booms.

For the Charing Cross bridge the value of C assigned by Professor Unwin is 1,880, and the depth measured between the centres of gravity of the booms is $\frac{1}{12 \cdot 8}$ of the span, as before. Therefore, if the strain s be again taken as 4 tons per square inch, the formula after reduction becomes $\frac{W L}{589 - L}$, and the limiting span is 589 feet.

The rule laid down by Mr. Benjamin Baker, M. Inst. C.E., in his "Long-span Railway Bridges,"[2] is $W \times \frac{t}{T - t}$, t being the strain in cwts. per square inch due to the weight of the girder itself, and T the strain in cwts. per square inch due to the entire load. His formula for the value of t in a lattice girder is,

$$0 \cdot 03 \frac{L^2 x + 2 L y d}{4 d},$$

in which d is the depth in feet at the centre, and x and y are coefficients depending upon the practical construction of the flange and web respectively, x being 0·93 and y being $2 \cdot 7 + 0 \cdot 001$ L.

Inserting the value of t found by this formula for the case of a girder the depth of which is $\frac{1}{12 \cdot 8}$ of the span, and reducing, the following quadratic equation is arrived at:—

$$Q = 0 \cdot 000001875 L^2 + 0 \cdot 001623 L.$$

Let Q = 1.

Then L = 417 feet, the limiting span.

For comparison with these results, it is now proposed to find a rule for the weight and limiting span of a lattice girder whose depth is $\frac{1}{12 \cdot 8}$ of the span, as before, by means of an application of the formula at the commencement of this Paper, using the data supplied by the weight of one of the girders of the Charing Cross

[1] *Vide* p. 41.

[2] *Vide* pp. 7 and 15.

Digitized by Google

bridge, with its load and span, as stated by Mr. B. B. Stoney, M. Inst. C.E., in his "Theory of Strains."[1]

Let the weight of any girder = g, its span = l, and the external load = w.

Then $\frac{w\,Q}{1-Q} = g$, whence Q for the span $l = \frac{g}{w+g}$; Q for any other span $L = \frac{g\,L}{(w+g)\,l}$; the limiting span $S = \frac{w+g}{g}\,l$, and $\frac{W\,L}{S-L}$ = the weight of any other girder of the same proportions carrying any load W.

Also, when the external load is proportional to the span, as in the case of most bridges, and of roofs having principals the same distance apart in each instance; if G = the weight of any other girder, &c., of the same proportions, $G = \frac{w\,L^2}{(S-L)\,l}$.

The following details are quoted by Mr. Stoney:—Weight of girder, deducting end pillars, 184 tons; load on girder, 553·33 tons, exclusive of cornice, handrail, fish-plates, bolts, spikes, chairs for rails, hoop-iron tongue and bolts for planking, and ballast. Span of girder, 154 feet. Calling the total external load 640 tons,

$$\frac{W\,L}{\left(\frac{640+184}{184}\times 154\right)-L} = \frac{W\,L}{688-L}$$

the weight of any other girder of the same proportion carrying any load W, and the limiting span is 688 feet (the weight here found is that between bearings only).

Summary.	Limiting Span. Feet.
Anderson (Malahide Viaduct)	747
Buck (Charing Cross Bridge)	688
Unwin („ „)	589
Baker	417

Now, however useful such formulæ may be for the purpose of rough estimation, and for affording an approximate weight upon which to base, in the first instance, the calculations for a bridge or roof, there can be no doubt that, when the span is considerable, a great deal of time is usually consumed in afterwards so adjusting

[1] *Vide* p. 588.

Digitized by Google

the final weight of the structure, that the strains per square inch shall neither exceed nor fall below the limiting strains; their scope also is necessarily very restricted. A system seems therefore to be called for by which, during the process of designing the structure, it may acquire, by successive accretions, due strength in each of its members; and, after a short reference to the formula of Professor Rankine, for use in designing girders, the objections to which will be pointed out, the Author proposes to describe a system which appears to fulfil the desired end.

Professor Rankine's formula, upon which he bases the proportions of each part of the girder, stands thus:—

$$B = \frac{B' s_1 W'}{s_1 W' - s_2 B'}$$

W′ being the external working load, s_1 its factor of safety, s_2 a factor of safety suited to a steady load, B′ the weight of the girder as computed by considering the external breaking load alone, $s_1 W'$; and B the total weight of the girder.

The whole of the external load is here considered as a moving load, the only fixed load being that of the girder itself. Now, in the first place it is certain that in a large bridge a great part of the load is fixed, and secondly, the moving load cannot be considered as provided for merely by the use of a factor of safety, the material introduced to meet the requirements of the moving load being distributed differently to that necessary for the fixed load. In fact, such a procedure is not applicable to open girders of any kind.

The method proposed by the Author for proportioning the different members of a framed girder, or roof principal, of any materials, is based upon the following considerations:—

Let the fixed distributed load = W, and W Q = a, as before.

Then, as before, $\frac{W a}{W - a}$ = the total weight of a girder of the strength required to carry W, and its own weight in addition.

Let b = the weight of the additional material necessary to enable the girder to carry the moving load, but not the weight b in addition.

Then, by proportion, $\frac{(W + b) a}{W - a}$ = the weight of a girder of the strength required to carry $W + b$, and its own weight in addition.

There still remains the increment b, hitherto only considered as part of the fixed load, which must be retained to support the moving load.

Digitized by Google

Therefore the total weight of the girder becomes

$$\frac{(W+b)\,a}{W-a}+b;\ \text{or}\ \frac{W(a+b)}{W-a},$$

considered for practical purposes as consisting of the following elements:

$$\left(a\times\frac{W}{W-a}\times\frac{W+b}{W}\right)+b,$$

or c being the weight of a girder of the strength required to carry $W+b$, but not its own weight in addition; and equal to $\frac{(W+b)\,a}{W}$

$$\frac{(W+b)\,c}{(W+b)-c}+b=\text{the total weight of the girder;}$$

consisting of the following elements,

$$\left(c\times\frac{(W+b)}{(W+b)-c}\right)+b.$$

The application is as follows:—

WHEN THERE IS NO MOVING LOAD.

(1.) Find the dimensions of each part of a girder of the strength required to carry the fixed load W, but not its own weight in addition, and note the sectional area of each member. Let the weight of this girder = a.

(2.) Multiply the sectional area of each member by $\frac{W}{W-a}$.

WHEN THERE IS A MOVING LOAD OR WIND PRESSURE ACTING LONGITUDINALLY, AS IN THE CASE OF A ROOF PRINCIPAL.

For Large Structures.

(1.) Find the dimensions of each part of a girder of the strength required to carry the fixed load W (including, in a bridge, its proportion of the floor, lateral bracing, rails, &c.), but not its own weight in addition, and note the sectional area of each member. Let the weight of this girder = a.

(2.) Multiply the sectional area of each member by $\frac{W}{W-a}$ (this step being taken at once, in some cases reduces the additional material for stiffening the struts accruing from the next steps).

Digitized by Google

(3.) Find the additional material required in each member to enable the girder to carry the moving load (in a roof to resist the action of the wind), and also in any new members which may be required for the same purpose, and note the sectional area of each member. Let the total weight of this additional material = b (not to be added).

(4.) Multiply the sectional area of every member, except the new ones, by $\frac{W + b}{W}$.

(5.) Add the additional material found in (3), assigning to each member the increment of sectional area due to it, and inserting the new members, if any.

For Small Structures.

(1.) Find the dimensions of each part of a girder of the strength required to carry the moving load, but not its own weight in addition, and note the sectional area of each member. Let the weight of this girder = b (merely note this).

(2.) Find the dimensions of each part of a girder of the strength required to carry $W + b$, but not its own weight in addition. Let the weight of this girder = c.

(3.) Multiply the sectional area of each member as found in (2) by $\frac{W + b}{(W + b) - c}$.

(4.) Add the material found in (1) allotting to each member the increment of sectional area due to it. If (1) has more members than (2), insert the additional members.

Digitized by Google

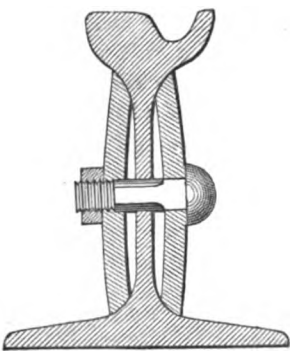
(*Paper No. 1809.*)

"Extension of the Dundee Street Tramways."

By ANDREW GREIG, Assoc. M. Inst. C.E.

THE Dundee Police Commissioners accepted tenders for the extension of the tramway system in December 1878. The first section was for 1 mile 1,140 yards of double line of tramway, and 1 mile 5 yards of single line, according to the designs of Mr. William Mackison, Burgh Surveyor. The double lines have been constructed between Dundee and the village of Lochee, along the Lochee Road. The single line is the Perth Road extension. The lines are laid to a gauge of 4 feet 8½ inches, with a 4-foot way; and the rolling surface of the rails is 1½ inch. The rails are of steel, made by the Bessemer process from a mixture of the best English Hæmatite brands and Spiegeleisen, cast into ingots of sufficient weight, and have the web perforated according to Gowans' system (Fig. 1). They weigh about 80 lbs. per lineal yard, are 7 inches high, and in lengths of 24 feet and upwards. An allowance of 10 per cent. was made for lengths of 18 feet and upwards. The bed of the rail, being 6 inches broad, gives a bearing of fully 1½ inch on each side for the paving setts. This section of rail never having been previously rolled, considerable trouble and delay were experienced, especially in forming the grooves. After many experiments and much expense, caused by the necessity for the adoption of specially prepared rolls, the sections were satisfactorily completed. Formerly this kind of rail was made by rolling the head solid, and then planing out the groove. But this process was costly and tedious; and, besides, it broke the skin of the steel, and caused irregularities in the width of the lip and bearing surface. The perforations of the web are 4½ inches wide, the space between them being 3 inches, and they are intended

FIG. 1.



Digitized by Google

to add stiffness to the tramway, by allowing the concrete and grouting to pass through the rail, and bind it and the paving setts together. All the rails were sent to the ground straight, those required for curves being bent to the proper radii by strong cramps. This was easily accomplished notwithstanding the peculiar section of the rail.

The ground was excavated to the depth of 12½ inches below the finished surface of the roadway. The bottom of the track was cleared of soft and unsuitable material, and then levelled and beaten to secure a solid and uniform bed. On this was laid a foundation of concrete 6 inches in thickness, composed of 1 part of Portland cement, 2 parts of clean sharp freshwater sand, and 4 parts of clean whinstone metal, broken to pass through a 2-inch ring. The rails are so laid that the upper surface of the bottom flange is flush with the top of the concrete foundation, and they are carefully levelled and solidly bedded underneath with cement mortar. They are joined at the ends with fish-plates 18 inches long, 5 inches broad, and ½ inch thick. Each pair of fish-plates is secured by four bolts and nuts, the bolts being 2¾ inches long, ⅝ inch thick, and square under the head. The paving setts laid between the rails and on the outside are of whinstone, 6 inches deep, 6 to 12 inches long, and average 3½ inches in thickness. While the paving was going on, gauges were kept on the rails to maintain them in proper position, there being no tie-rods. The setts next the rails are bedded on cement mortar and sand, and the top of them is left as nearly as possible flush with the top of the rail. The other paving stones are bedded on a ½-inch layer of clean coarse freshwater sand, and well beaten down. Before the setts were laid, the sides of the rails were packed with Portland cement mortar. The setts were grouted with best bitumen manufactured from pitch, pure coal-tar, and creosote oil, in the proportions of 1 ton of pitch to 80 gallons of tar, and 20 gallons of creosote, or such other proportions as the engineer approved, these substances varying considerably in quality.

The steepest gradient is 1 in 18·5. The inclinations vary from 1 in 52 to 1 in 138. In the centre of the town a portion of the tramway is almost level.

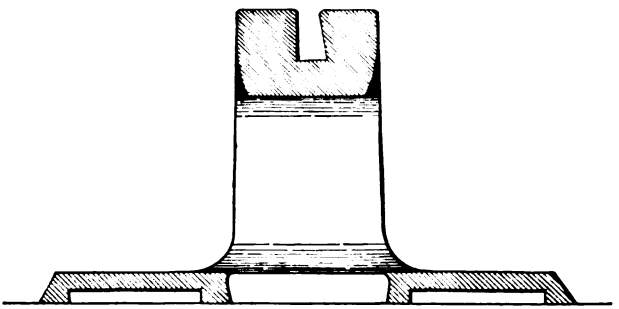
The second section, from the Post-office to the East end of the town, is double for a considerable distance. Its length is 2 miles 742 yards, taken as single line. At Victoria bridge a branch begins, and runs along Victoria Street and Arbroath Road to Baxter Park. The rails used for the lines leading northward are

Digitized by Google

similar to those already described, but as the web is not perforated, they are much stronger. They weigh about 82 lbs. per lineal yard, and were called "heavy rails" to distinguish them from Gowans' rails.

The branch is 847 yards in length, measured as single line, and has been constructed according to Mr. Mackison's system (patent No. 2894, dated 20th July, 1878). This system consists of two parts:—cast-iron tee sleepers and rolled rail fastened on the top. The sleepers weigh 120 lbs. each, are 3 feet 11 inches long, 11¼ inches broad across the bed-plate, 6 inches high, and are laid 1 inch apart at the ends (Fig. 2). They are of open make, the

FIG. 2.



rail-bed at the top being connected by vertical supports. The underside of the bed-plate is cast with recesses in it for the purpose of gripping more securely the cement mortar on which it is bedded (Fig. 3). The open spaces in the bed-plates, those between the vertical supports connecting the bed-plate with the rail-bed, and those between the paving setts next to the rail on each side, are packed with concrete. The greater part of the sleeper is therefore embedded in the concrete, and is held firmly in position. The rail-bed of the sleeper has a dovetailed groove for receiving the dovetailed tongue on the underside of the rail, and has inclined and slightly dovetailed recesses for fixing the keys (Fig. 4). The rails, weighing about 36 lbs. per lineal yard, are of rolled steel, and shaped at the bottom so as to fit exactly to the side of the groove of the sleeper, and have slot-holes pierced through the grooves at intervals for the insertion of the fixing keys. These keys are of wrought iron, 4 inches long, 1⅛ inch broad, average ⅜ inch thick at the centre, and are tapered and bevelled. They can be easily removed, so as to allow of the rails being taken off

Digitized by Google

and replaced without disturbing either the paving setts or the cast-iron sleepers.

The experience gained in rolling the other section of rails enabled the makers, Messrs. Brown, Bayley and Dixon, of Sheffield,

FIG. 3.

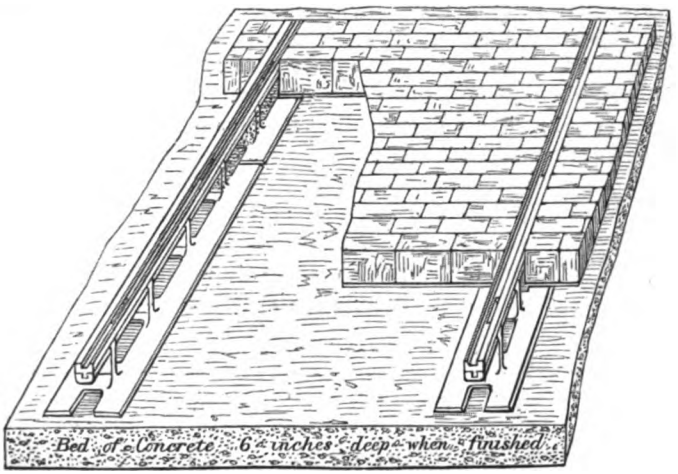
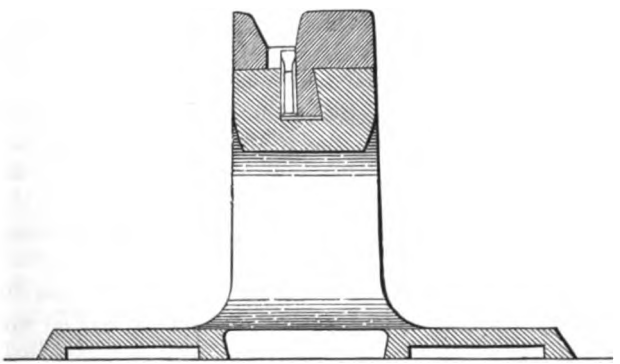


FIG. 4.



to manufacture this section with dovetailed tongue successfully, after a few trials. When the rails are fixed, that part of the grooves in the rail-beds of the sleepers not occupied by the tongues of the rails is filled with plastic British bitumen to keep out water and mud. The lengths of the rails are 20, 24, and 28 feet, less

Digitized by Google

¼ inch for expansion. An allowance of 10 per cent. was made for lengths of 16 and 20 feet, less ¼ inch. The gradients vary from 1 in 23 to 1 in 517.

The cost of the tramways laid with Gowans' rail was about £2 6*s*. 5*d*. per lineal yard of single line, or £4,085 1*s*. per mile. That of the tramways laid with the heavy rail was about £2 3*s*. 11*d*. per lineal yard of single line, or £3,867 2*s*. 4*d*. per mile. The cost of the tramway laid along Victoria Street to Baxter Park, according to Mackison's system, was about £2 8*s*. 10*d*. per lineal yard of single line, or £4,299 2*s*. per mile. This being the first contract for Mackison's system, and the quantity small, the rates were proportionately higher, special rolls having to be prepared. But a material reduction has recently been made in the manufacture of the sleepers and rails, as in the case of the contracts for Oldham, where a length of 7 miles has been laid.

The following are the rates for the various items in the contracts, arranged to show the cost per mile of single line :—

1. GOWANS' SYSTEM.

—	Quantity.	Rate.	—
		£. s. d.	£. s. d.
Lifting and carting away macadam, &c.	522 cubic yards	0 1 9	45 13 6
Excavation, &c.	1,108 „	0 2 0	110 16 0
Portland cement concrete 6 inches thick	782 „	0 17 0	664 14 0
Laying tramway, &c. . .	1,760 lineal yards	0 1 8	146 13 4
Paving, &c.	2,836 sq. yards	0 7 3	1,028 1 0
Paving on cement and sand next rails	1,564 „	0 7 7	593 0 4
Grouting joints of setts with bitumen	4,400 „	0 1 3½	284 3 4
Steel rails	125¾ tons	8 14 0	1,094 0 6
Wrought-iron fish-plates .	4¾ „	8 0 0	38 0 0
„ bolts and nuts	9 cwt.	0 11 0	4 19 0
Royalty at £75 per mile .	..	..	75 0 0
Cost per mile of single line (exclusive of points and crossings)	..	..	4,085 1 0

Digitized by Google

2. Heavy Rail.

—	Quantity.	Rate.	—
		£. s. d.	£. s. d.
Lifting and carting away macadam, &c.	522 cubic yards	0 1 6	39 3 0
Excavation, &c.	1,108 „	0 1 6	83 2 0
Portland cement concrete 6 inches thick	782 „	0 14 0	547 8 0
Laying tramway, &c.	1,760 lineal yards	0 1 6	132 0 0
Paving, &c.	2,836 sq. yards	0 6 10	968 19 4
Paving on cement and sand next rails	1,564 „	0 7 0	547 8 0
Grouting joints of setts with bitumen	4,400 „	0 1 3	275 0 0
Steel rails	129 tons	9 10 0	1,225 10 0
Wrought-iron fish-plates	4½ „	9 0 0	42 15 0
„ bolts and nuts	9 cwt.	0 13 0	5 17 0
Royalty	..	..	0 0 0
Cost per mile of single line (exclusive of points and crossings)	..	..	3,867 2 4

3. Mackison's System.

—	Quantity.	Rate.	—
		£. s. d.	£. s. d.
Lifting and carting away macadam, &c.	522 cubic yards	0 1 4	34 16 0
Excavation, &c.	1,108 „	0 1 7	87 14 4
Portland cement concrete 6 inches thick	782 „	0 14 6	566 19 0
Laying tramway, &c.	1,760 lineal yards	0 2 2	190 13 4
Paving, &c.	2,836 sq. yards	0 6 10	968 19 4
Paving on cement and sand next rails	1,564 „	0 7 0	547 8 0
Grouting joints of setts with bitumen	4,400 „	0 1 3	275 0 0
Sleepers (cast iron)	141½ tons	7 0 0	990 10 0
Steel rails	56½ „	9 10 0	536 15 0
Wrought-iron keys	19½ cwt.	1 6 0	25 7 0
Royalty at £75 per mile	..	..	75 0 0
Cost per mile of single line (exclusive of points and crossings)	..	..	4,299 2 0

The tramways have now been in operation for some time, and are giving great satisfaction. The wear and tear, however, of the stones next the rails, where the vehicular traffic is great, have been considerable, which seems to indicate that harder materials are required next the rails, and that it is not good to have these

Digitized by Google

stones too rigidly bedded. Where these setts have been seriously cut by the carriage and cart wheels, they have been replaced by others of the same kind, with Gowans' chilled-iron plates in the joints; or with creosoted beechwood blocks, with similar chilled-iron plates in the joints, bedded and stuffed with gravel not larger than common peas. The wooden setts give little frictional resistance to the ordinary traffic, and promise to answer well. Mackison's system is found to be smoother, more elastic, and more pleasant to run over than the other rails, which are very rigid.

Digitized by Google

(*Paper No. 1818.*)

"The Oxford and District Tramways."

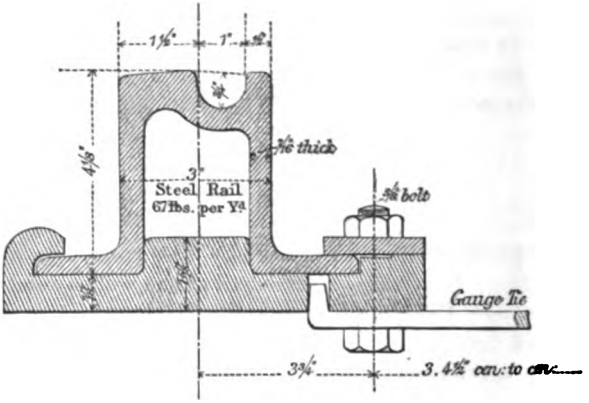
By JOHN BRUNTON, M. Inst. C.E.

THE City of Oxford, apart from the University, is a busy and thriving market town, and contains, with its extensive suburbs, a population of about forty thousand inhabitants. The railway stations are nearly a mile from the centre of the town, which has no omnibus communication either with the railways or with any of the populous outlying districts and suburbs. The tramway, which has now been opened for traffic, commences at the railway stations and, passing through Carfax and down the High Street, crosses over Magdalen Bridge, and along the Cowley Road, terminating for the present at the cricket grounds. A branch is in course of construction in a northerly direction, from Carfax towards the increasing suburb of Summertown, and further extensions are contemplated in other directions. The tramway is for the most part a single line, laid to a gauge of 4 feet, with passing-places at intervals of about 330 yards, but as the streets and bridges of the old city are in some places very narrow, a double line of tramway has been laid where the width is not sufficient to admit a single line in the centre of the street. Thus the roadway over Magdalen Bridge, for a length of about 150 yards, has a width of only 16 to 18 feet between the footways, and it was anticipated by the road authorities that the traffic would be so impeded by the tramway as to necessitate the widening of the bridge; but by laying a double line along the whole length of the bridge, the apprehended obstruction of the traffic has been avoided, as the tramcars follow the traffic in each direction. The permanent way is of simple and somewhat novel construction, and was designed for this tramway by Messrs. J. Brunton and T. Claxton Fidler, MM. Inst. C.E., and has been successfully executed under their superintendence. No timber or iron sleepers are employed, but the way consists simply of a pair of steel rails of bridge section, having a continuous bearing upon the substructure of concrete. Thus there are no fastenings of any kind except at the joint of the rail, and at this point no attempt has been made to preserve the transverse strength by fishing the joint with deep fish-plates, but the meeting ends of the rails are

Digitized by Google

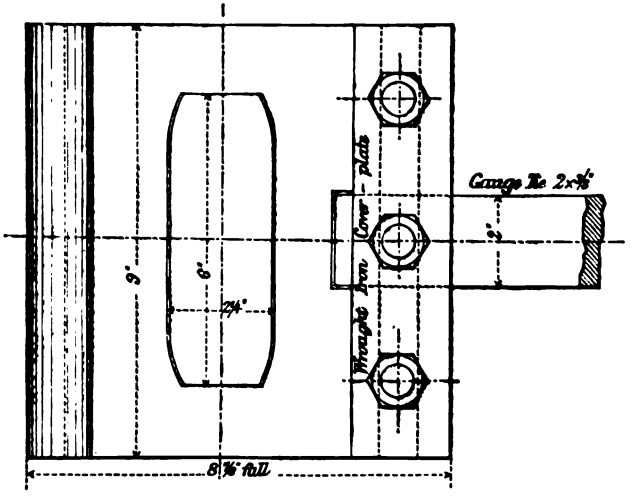
held in accurate adjustment, both vertically and transversely, by cast-iron joint-shoes, and kept to gauge by a wrought-iron tie. The steel rails weigh 67 lbs. to the yard, and are 18 feet in

Fig. 1.



Section of Rail and Shoe.

Fig. 2.



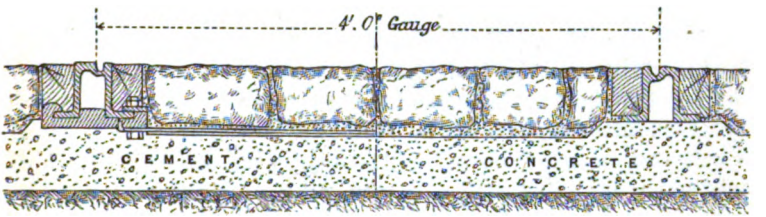
Plan of Cast-Iron Joint Shoe.

length, and of the section shown in Fig. 1. The width of the groove is 1 inch; the sides of the bridge-section are slightly battered so that the rail may come freely from the rolls, and in

Digitized by Google

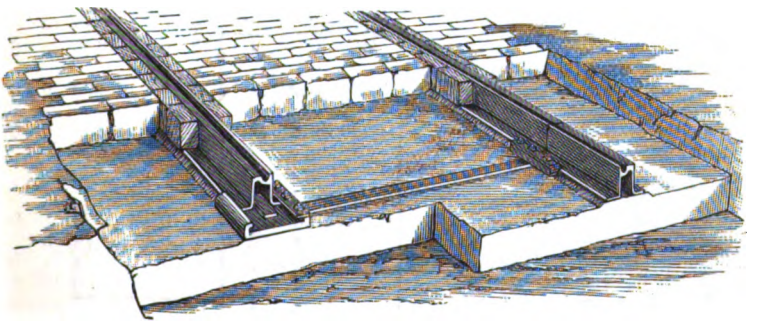
practice no difficulty has been experienced in rolling them, and no punching or drilling is required. The joint-shoes are of cast iron, and weigh 22¾ lbs. each; the ends of the rails are kept in adjustment transversely by the central projecting rib of the shoe, which fits accurately in the hollow of the bridge-rail, the rib having a slight taper to correspond with the sides of the rail. The vertical adjustment is effected by clamping the inner flange of each rail down upon the base of the shoe, while the outer flanges are held under the projecting lip which runs along the outer edge of the

FIG. 3.



Cross Section.

FIG. 4.



shoe. The foot of each rail having been slid under this projecting lip, the rails are firmly brought down upon the shoe, and secured by a covering strip of wrought iron 2½ inches wide, placed over their inner flanges, and bolted down by three ⅝-inch bolts, as shown in Figs. 1 and 2. The central bolt fixes at the same time the gauge-tie, which is a plain wrought-iron bar 2 inches by ⅜ths of an inch, the ends being turned up as lugs, which enter into holes cast in the base of the joint-shoe. This fastening has in practice been found sufficient to preserve the joints in adjustment of line and level, while the great stiffness of the rail and its continuous

Digitized by Google

bearing upon carefully packed concrete have preserved the continuous line and level of the tramway under the heaviest traffic to which it has been subjected. The tramway is paved with 5-inch granite sets laid upon a bed of concrete (Figs. 3 and 4), but on each side of the rail-head wood paving is inserted 2½ inches in width, the blocks being bedded directly upon the flange of the rail. The points and crossings are of chilled cast iron; the curved rails for the passing places and curves of the tramway were bent cold at the works, to carefully-prepared templates, and sawn to special calculated lengths, and the crossings having been accurately made by Messrs. Ransomes and Rapier, the sidings were generally laid in place by fitting the parts together without bending or cutting. The laying of the tramway was commenced in June 1881, and the main line was opened for public traffic on the 1st of December, the works having been successfully completed by the contractor, Mr. E. D. Mathews, Assoc. Inst. C.E. The actual cost of any tramway will always vary according to local conditions and fluctuations in the price of materials; but the average cost of this system for a mile of single line may be taken to be as follows:—

				£.	s.	d.
Excavation	1,175 cubic yards	at	2 0	117	10	0
P. C. Concrete	587 „ „	„	15 0	440	5	0
Paving between the rails and 1 foot 6 inches on each side, including wood paving	3,960 square „	„	10 0	1,980	0	0
Laying permanent way	1,760 lineal „	„	1 6	132	0	0
Permanent Way Materials.	Tons. Cwt.					
Steel rails	105 6	at	8 10 0	895	1	0
Cast-iron joint-shoes	6 0	„	7 0 0	42	0	0
Wrought-iron coverplates	0 9	„	9 0 0	4	1	0
„ bolts	0 8	„	14 0 0	5	12	0
„ gauge-ties	1 4	„	9 0 0	10	16	0
Total weight	113 7	Total cost		£3,627	5	0

Digitized by Google

(*Paper No. 1822.*)

"Results of Experiments with Portland Cement gauged with Sea and Fresh Water under different conditions."

By Henry Faija, Assoc. M. Inst. C.E.

In the discussion upon Mr. Grant's Paper on Portland cement, the Author mentioned that he was then commencing a series of experiments, having for their object the determination of the behaviour of cement when gauged with sea water and when placed in sea water.[1] Those experiments having now been completed, he desires to place the results before the Institution.

Three hundred and sixty briquettes were gauged and treated as follows:—

No. 1	was gauged with	sea	water and placed in	sea	water.
„ 2	„	„	„ „	„	fresh „
„ 3	„	fresh	„ „	„	sea „
„ 4	„	„	„ „	„	fresh „
„ 5	„	sea	„	left	air.
„ 6	„	fresh	„ „	„	„

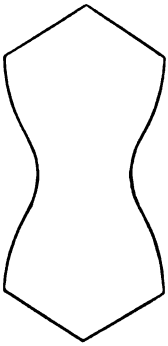
Sixty briquettes were gauged and treated in each of the above ways, and ten of each were tested for tensile strength in a Michele machine, after seven days, twenty-eight days, three months, six months, nine months, and one year respectively.

To arrive at the true comparative value under the different conditions, it was considered necessary that the cement in each instance should be gauged with the same amount of water, and that the whole of the briquettes should be gauged within a few days of each other, so that no variation in result could be attributable to any depreciation or alteration in the nature of the cement; also that the same time should elapse between gauging the briquettes and placing them in water, and in fact that all the details of gauging and manipulation should be, as nearly as possible, identical.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxii., p. 187.

Digitized by Google



The briquettes had each a sectional area of 1 square inch, and their form was an adaptation of Mr. Grant's which the Author has adopted in his testing-room, and from first to last they took twelve days to gauge. The sea water used in the experiments was procured from Brighton in 3-gallon wooden kegs, the fresh and sea water tanks being renewed every fortnight. The cement came under the Author's notice in the ordinary way of his practice, to report upon its value, and was not selected as likely to give extraordinary results; and it can at best be considered only as a fair sample of ordinary commercial manufacture.

Weight per striked bushel		112 lbs.
Specific gravity		2·97
Fineness	Residue after sifting through a No. 25 sieve	0 per cent.
	" " " " 50 "	18 "
	" " " " 70 "	25 "
Time taken to set when gauged with fresh water		25 minutes.
" " " " " sea "		120 "

Colour, a fairly cold grey but rather light.

The amount of water used for gauging, both sea and fresh, was 17·24 per cent., and the briquettes were in each case removed from the moulds and placed in their respective tanks in twenty-one hours after gauging.

In comparing these results (see Table next page), it would seem desirable to consider Nos. 1, 2, and 3 with No. 4, that being the result of an experiment carried out in the ordinary way for determining the value of a cement, viz., by gauging with fresh water and placing the briquettes when set in fresh water. Nos. 5 and 6 may be considered only so far as they compare with each other; they show that although the use of sea water for gauging seems to retard the setting or hardening of cement, it eventually gives it greater strength than when gauged with fresh water, both samples being allowed to remain permanently in the air. Referring again to No. 4 as representing unity when immersed in either sea or fresh water, the samples gauged with sea water, and when set immersed in either sea or fresh water, show a falling off in tensile strength, while the samples gauged with fresh water, and when set immersed in sea water, show a decided and marked increase in strength. It may therefore be deduced that the salts in sea water have a damaging effect on cement gauged with sea water, and afterwards immersed in either sea or fresh water, but a beneficial one when the cement

Digitized by Google

RESULTS of TESTS. AVERAGE of TEN BRIQUETTES in each CASE.

Number.	Tensile Strength in lbs. per Square Inch.	Proportionate Value at each Date, No. 4 being taken as the Unit.	Increase per cent. in Strength from last Date of Testing.	Total Increase per cent. between the Seven Days Test at — Months.	Order of Value at each Date.
			Seven days test.		
1	470	0·918	..	..	4
2	425	0·830	..	..	5
3	634	1·239	..	..	1
4	**512**	**1·000**	..	..	**3**
5	418	0·816	..	..	6
6	526	1·027	..	..	2
			Twenty-eight days test.		
1	687	1·110	46·170	46·170	2
2	533	0·861	25·412	25·412	6
3	755	1·220	19·085	19·085	1
4	**619**	**1·000**	**20·898**	**20·898**	**5**
5	651	1·052	55·742	55·742	4
6	653	1·055	24·144	24·144	3
			Three months test.		
1	820	1·235	19·360	74·468	3
2	745	1·122	39·756	75·294	4
3	882	1·328	16·821	39·117	1
4	**664**	**1·000**	**7·270**	**29·687**	**6**
5	874	1·316	34·255	109·090	2
6	681	1·025	4·288	29·468	5
			Six months test.		
1	847·5	0·999	3·354	80·319	4
2	765	0·902	2·685	80·000	6
3	949	1·119	7·596	49·684	1
4	**848**	**1·000**	**27·711**	**65·625**	**3**
5	932	1·099	6·636	122·966	2
6	838	0·988	23·054	59·315	5
			Nine months test.		
1	847	1·005	−0·598	80·213	4
2	749	0·888	−2·093	76·235	6
3	993	1·177	4·636	56·625	3
4	**843**	**1·000**	**0·589**	**64·648**	**5**
5	1,070	1·269	14·807	155·965	1
6	1,040	1·234	24·105	97·719	2
			Twelve months test.		
1	835	0·992	−1·417	77·660	5
2	764	0·910	2·003	79·765	6
3	1,064	1·260	7·150	67·823	2
4	**840**	**1·000**	**−0·356**	**64·062**	**4**
5	1,120	1·300	4·673	165·550	1
6	1,060	1·262	1·923	101·521	3

Digitized by Google

is only exposed to the action of the air, and further that the same salts have a highly beneficial effect when acting on cement gauged with fresh water. The conclusion therefore arrived at is that for all marine purposes those portions of the work which are above high water should be gauged with sea water, while those portions below the water level should be gauged with fresh water.

The Author believes that these are the first experiments carried out in a systematic manner, comparing the strength of a cement under these different conditions; and that the difference in the results from those given by Mr. Dyce Cay[1] are due to the latter having used a larger quantity of water when gauging with fresh water than when gauging with sea water, a procedure which would naturally lead to the results obtained, and for which in the Author's opinion there is no object, as a cement will gauge with fresh water just as easily as with sea water.

It may perhaps be suggested that the experiments should have been extended over a longer period, but there is no reason to suppose that any materially different result would have been obtained. A matter more to be regretted is that only one sample of cement has been experimented upon, as another sample might not give the same result at the earlier dates though it might not vary much at the later ones. Still the Author trusts that the experiments will be of value to those who have to use cement under these conditions, and that it may lead to further experiments being made on a larger scale.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxii., p. 210.

Digitized by Google

(*Paper No. 1838.*)

"Steel for Tires and Axles."

By BENJAMIN BAKER, M. Inst. C.E.

THE present experience with reference to the use of steel in tires and axles is so great that it might not unreasonably have been assumed that, by common consent, engineers and manufacturers would have arrived at certain definite qualities for these purposes respectively. To ascertain whether this was so the Author recently obtained half-a-dozen pairs of tires and axles from as many of the leading makers at home and abroad, and submitted the same to the tests briefly detailed hereafter. No particular mode of manufacture was specified, nor were any conditions imposed as to price.

The results were startling and unsatisfactory. Not only was there no uniformity in the quality of steel supplied by the several makers, but even the two tires of the same maker, as a rule, differed widely in behaviour under test. Thus the tensile strength of the steel in the twelve tires ranged from 32·25 tons to 49·5 tons per square inch, and the extension from 5 per cent. to 25 per cent., whilst under the "drop-test" one tire might fail at the second blow of a weight of 1 ton falling 10 feet, and the next only do so at the twelfth blow from the increased height of 30 feet, the respective bendings before fracture varying from no less than $\frac{9}{16}$-inch to 28 inches in the 3-feet tire.

Similarly the tensile strength of the steel in the axles ranged from 27·35 tons to 40·7 tons per square inch, the extension from 17·6 per cent. to 23 per cent., and the number of blows sustained before fracture from 3 to 35. It will be seen hereafter that a high rate of elongation affords no guarantee that a tire or axle will behave well under the drop-test, and probably no efficient substitute could be found for the rough and ready test of endurance afforded by the bending and straightening blows of a weight of 1 ton falling 20 or 30 feet.

TIRES.

The tests applied were:—

(1) A steady bending pressure, to ascertain the elastic resistance of the tire to collapse.

(2) Successive blows from a weight of 1 ton falling 5, 10, 15,

Digitized by Google

20, 25, and 30 feet, to determine the endurance of the tire under shocks and blows.

(3) A steady pulling stress to ascertain the ultimate tensile strength and elongation of samples of steel cut from the tires.

The tests were conducted in all instances either by the Author, or by Professor Kennedy, M. Inst. C.E.

The tires were of ordinary cross section, and weighed on the average 427 lbs. each. The two samples of the several makers are referred to as a_1 and a_2, b_1 and b_2, &c., in the ensuing Table.

—	Approximate elastic resistance to collapse.	Permanent Set under 40 Tons.	Ultimate Tensile Strength.	Percentage of Elongation in Length of 5 Inches.	Extent of Bending under falling Weight.		
					After Third Blow.	After Fifth Blow.	After Eighth Blow.
		Inch.	Tons per Sq. Inch.	Per Cent.	Inches.	Inches.	Inches.
a_1	38 tons	0·05	49·50	14·0	2⅜	6⅞	13⅞
a_2	not taken	..	49·48	14·0	2⅜	6⅜	13⅞
b_1	38 tons	0·05	46·43	18·6	3	7 3/16	15⅜
b_2	not taken	..	40·9	23·6	3	7½	15⅜
c_1	„	..	44·21	8·0	3 3/16	broke at 4th	..
c_2	36 tons	0·07	42·48	5·0	4⅛	broke	..
d_1	not taken	..	42·51	19·6	broke	..	..
d_2	33 tons	0·18	37·36	5·8	broke at 2nd	..	..
e_1	36 „	0·05	38·85	24·4	3⅜	broke	..
e_2	not taken	..	38·01	25·0	4	10⅛	20⅜
f_1	„	..	34·67	14·5	5 5/16	broke	..
f_2	29 tons	0·60	32·25	12·0	5⅛	11⅞	24⅜

NOTE.—The moment of resistance of the tire being 5, the bending moment 5 W, and the average elastic tensile resistance of the steel 22 tons, the elastic resistance to collapse might have been wrongly calculated to be 22 tons also; but, for reasons set forth in the Author's Paper on "The Practical Strength of Beams,"[1] it would have been more correctly assumed at about 22 tons × 1·7 = 37 tons.

AXLES.

The tests applied were :—

(1) Successive bending and straightening blows from a weight of 1 ton falling 5, 10, 15, and 20 feet, and continued at the latter

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxii., 251.

Digitized by Google

height until failure occurred. The axles were placed on solid bearings 3 feet apart, and were turned half round after each blow.

(2) A steady pulling stress to ascertain the ultimate tensile strength and elongation of samples of steel cut from the axles.

The axles were nominally 4 inches in diameter, but ranged from that figure to nearly $4\frac{1}{2}$ inches. The makers are referred to under the same letters as in the previous Table.

—	Diameter of Axle.	Ultimate Tensile Strength.	Percentage of Elongation in Length of 5 Inches.	Extent of Bending under Falling Weight.		Number of Blows Causing Failure.
				10 Feet.	20 Feet.	
	Inches.	Tons per Square Inch.	Per Cent.		Inches. Inches.	
a	4	27·79	22·0	$2\frac{7}{8}$	$4\frac{3}{4}$ to $5\frac{1}{8}$	35
b	$4\frac{1}{2}$	40·7	20·6	$1\frac{1}{8}$	$3\frac{3}{4}$	8
c	$4\frac{1}{8}$	36·85	22·0	$2\frac{1}{2}$	broke at 15 ft.	4
d	$4\frac{1}{16}$	27·35	23·0	3	Inches. Inches. $4\frac{5}{8}$ to $5\frac{7}{8}$	34
e	$4\frac{1}{16}$	31·15	19·4	$2\frac{7}{8}$	$4\frac{1}{2}$	14
f	$4\frac{1}{8}$	32·34	17·6	$2\frac{1}{8}$	$3\frac{5}{8}$	6

Comparing the above with the previous Table the following conclusions would appear to result.

(1) Maker *a* adopted for his tires a steel of high tensile resistance, uniform in quality, with a medium amount of elongation, and capable of standing several blows from 1 ton weight falling from the full height of 30 feet. For his axles he used very mild steel, having 43 per cent. less tensile resistance and 50 per cent. more elongation than the tire steel, and of great endurance under the drop-test.

(2) Maker *b* apparently preferred a medium quality of steel for both tires and axles, and as a consequence his tires were not so hard and strong as the *a* tires, and presumably not so durable, whilst his axles were much harder, and failed with comparatively few blows under the drop-test.

(3) Maker *c* supplied a couple of moderately hard tires, but the steel had a dangerously low rate of elongation, and failure quickly resulted under the drop-test. The axle was somewhat softer than the tires, and had a satisfactory rate of elongation, but signally failed to withstand the shock of the falling weight.

(4) Maker *d* used a fairly hard but very untrustworthy quality of steel for his tires, as evidenced by the wide difference in the

Digitized by Google

ultimate strength and elongation of the two tires, and by the snapping of both with a slight blow under the drop-test. His axle, on the other hand, was of mild steel of suitable tensile strength and elongation, and behaved exceptionally well under the drop-test.

(5) Maker *e*, though his tire steel was of uniform tensile strength and elongation, did not succeed in securing uniformity of quality. Although the steel was too soft for good wearing purposes, and had a high rate of elongation, one of the tires failed with half the number of blows that the second and several other much harder tires sustained. The axle was somewhat hard, and suffered correspondingly under the drop-test.

(6) Maker *f*, like maker *b*, apparently used the same steel for both tires and axles, but of a much milder quality. Notwithstanding its softness, the steel did not prove uniform and trustworthy, as the axle broke at the sixth blow with a bending of $3\frac{5}{8}$ inches, whilst one tire bent $27\frac{1}{8}$ inches before fracture and the other only $8\frac{5}{8}$ inches.

It may be interesting to remark that samples of steel from axles supplied in 1868 by maker *a*, and in 1862 by maker *b*, were tested by Herr A. Wöhler in his celebrated series of experiments on the "fatigue of metals."[1] At the dates named it may be inferred that the former maker was in the habit of supplying steel for axles having a tensile strength of from 26 to 29 tons per square inch with a rate of elongation of from 16 to 20 per cent., and the latter maker steel having what would now be considered in the case of axles the dangerously high tensile resistance of from 48 to 50 tons with an elongation of from 11 to 18 per cent.

The conclusion the Author draws from his experiments is, that it would be imprudent, on the part of an engineer, to leave the quality of steel either for tires or axles to the discretion of a manufacturer, or to forego the most rigid system of inspection. An occasional test is of little use, because the most inferior materials may at times accidentally produce a good result; but to ensure a good result and perfect uniformity in quality the best materials and the greatest care in manufacture are absolutely essential. The tabular results show that a sample of steel may be cut from a tire or axle and be tested with perfectly satisfactory results as regards tensile strength and elongation, and yet that the tire as a whole may fail under moderate shocks, either on account of the steel being inferior in some respect which those tests do not detect, or

[1] *Vide* Über die festigkeitsversuche mit Eisen und Stahl. Berlin, 1870.

Digitized by Google

from its not being uniform in quality throughout. Similarly as regards the axles. Mildness, great elongation, and an ability to withstand the "temper" test, do not always ensure the steel being able to withstand the shocks and jars of traffic. Half-a-dozen specimens may be cut for testing from a given axle and yet some weak spot in it escape notice. It has been frequently proved, both by chemical analysis and by physical tests, that a bad ingot, or a steel rail rolled from it, differs widely in composition and strength from point to point, and the same holds good with a bad steel axle. A severe blow, either under the drop-test or in actual working tries every part of the tire or axle, and finds out the weak spot, if there be one, whereas by almost any other test there would be a chance of the fault remaining undetected.

Assuming the steel to be of good materials and to be uniform in quality, it remains to be decided what degree of hardness is most desirable in the case of tires and axles. Experience has proved that steel, having a tensile strength as high as 50 tons per square inch, is quite trustworthy for use in tires in ordinary climates if the tires will stand a proper drop-test. Similarly experience in ship-building yards and elsewhere has led to the specification of mild steel having a tensile strength of from 26 tons to 32 tons per square inch, that quality being found best able to sustain without injury the contingencies of working. Probably a limit of 46 tons to 50 tons in the case of tires and of 27 tons to 30 tons in that of axles, with proper drop-tests, would, on the whole, be the best to specify in order to secure the most suitable steel for the respective purposes.

Digitized by Google

(*Paper No. 1843.*)

"The Current-Meter of Professor A. R. Harlacher."

By RICHARD BLUM, City Engineer, Leipzig.

EVERY one who has had occasion to measure the velocity of water in rivers or tidal currents has complained, and with reason, that the instruments in use for that purpose are inconvenient, and do not give results scientifically satisfactory. With Woltmann's Current-Meter, which has been chiefly used, the operation of determining the velocity is delayed and rendered laborious, by the necessity of removing the meter from the water for every reading of the number of rotations. Nevertheless, this instrument is the only one which can be used in large and deep rivers. One cause of the inaccuracy of the results obtained by this instrument is that considerable time is required to determine the velocity at different depths in any vertical section, and a still longer time to repeat this operation at a sufficient number of verticals to give a good value of the mean velocity at the cross section. In most cases the level of the water-surface varies during the operations, and thus the different velocities are not ascertained under the same conditions, and cannot agree accurately with each other. Some engineers, therefore, have tried to shorten the time required for such measurements, by improving the method of counting the rotations of the meter. Thus Mr. Ritter (Engineer-in-Chief, Ponts et Chaussées), at Paris, in 1859, and Mr. Henry, when measuring rivers flowing into Lake Erie in 1867, adopted a method for electrically registering the number of rotations of the meter, and dispensing with the necessity for lifting it out of the water for each reading. Mr. Ritter especially took great pains to improve the current-meter in this way, but arrived at no satisfactory results. Professor Harlacher, of the Technical High School at Prague, was the first to construct a current-meter which obviates all the difficulties and drawbacks of the instruments previously employed. The Harlacher Current-Meter, permits the velocity to be determined in the shortest

Digitized by Google

possible time. Before describing the details of the instrument a general statement may be given of its merits and advantages.

The current-meter is a screw meter on the same general principle as the old instrument of Woltmann. Connected with it is an indicator, or clock, actuated electrically, which shows the number of rotations of the screw. The meter is suspended in the water by a cord so that it can be raised or lowered at will. It can therefore be readily placed at any depth or allowed to descend slowly and uniformly from the surface of the water to the bed of the river. The instrument is never taken out of the water until the measurements in one vertical of the section are completed, because the electric registration of the rotations is effected above water. When the mean velocity at one vertical is required, that is most easily obtained by allowing the meter to descend regularly and slowly along that vertical from the surface of the river. The number of rotations on the electric indicator and the time are noted. Dividing the rotations by the time, the mean rate of rotation of the meter, corresponding to the mean velocity of the stream, is found. The result is identical with that obtained, more laboriously, by measuring the velocity at a number of equidistant points on the vertical and taking the average of the velocities. It is therefore needless, in future, to adopt the time-wasting method of observing a number of velocities at different points in each vertical, in the cross section of the stream. It is only necessary to allow the meter to descend once along each vertical from the water surface to the bottom. Thus the whole of the measurements for a cross section can be completed in as many minutes as hours would have been required with the old form of the Woltmann Meter, and the results will be more reliable, because for so short a time the general conditions of flow of the river will have remained constant. Variations of velocity due to variation of the level of the river are virtually eliminated when the Harlacher Meter is used.

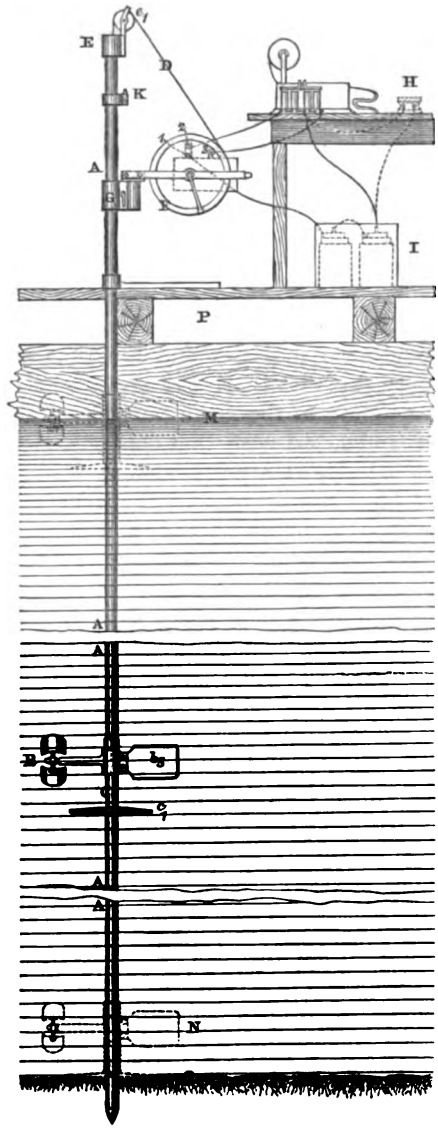
It is unnecessary to describe all the stages in the invention of the present form of the Harlacher Meter. It is sufficient to say that Professor Harlacher worked for several years at its improvement, and that his success was acknowledged by the award at the Paris Exhibition of two Gold Medals.

The Harlacher Meter is constructed as follows:—For the movable staff, on which the Woltmann Meter is fixed, an immovable staff or rod is substituted, which is planted firmly in the bed of the river, and along which the meter slides up and down during the observations on any one vertical. This rod is a cast-iron tube

Digitized by Google

with a solid point at the lower end A, A (Fig. 1). The other parts of the apparatus, except the electric battery and indicator, are fastened to the tube, so that the whole can be moved from one vertical to another without having to be taken apart. The screw of the meter, B, is two-bladed. For very small velocities it would be preferable to adopt a four-bladed screw of larger diameter. The screw is fixed on a steel shaft b, (Fig. 2), which has an eccentric enlargement at one point b_3. This makes contact with the steel spring, b_4, at each revolution of the meter. These contacts complete the electric circuit, and the current which passes actuates the electric clock or indicator. The weight of the screw B, the shaft b, and the brass box b_2, which carries the shaft, is balanced by a counter-weight b_5 (Figs. 1, 2 and 3). This keeps the axis of the instrument in a perfectly horizontal position. The screw, b_6, serves to regulate the pressure of the spring, b_4, while the two screws, b_7, fasten the spring to the brass frame which surrounds and protects the shaft. The shaft is square at the end which receives the screw, which is put on and held fast by a nut, b_8 (Figs. 2 and 3). The brass frame, b_2,

Fig. 1.



Digitized by Google

is fixed to a hollow cylinder, C. Below the hollow cylinder, C, is a plate, C_1 (Figs. 2 and 3), which prevents the instrument approaching too closely to the bed of the river, where it might be injured or retarded by obstacles. In the interior of the cylinder, C, there is a cylindric case, c_2 (Figs. 3, 4, and 5), in which a brass spring is fastened, and through which the pin, c_3, is carried. To this pin the end of the suspending rope, D, is fastened. The internal diameter of the cylinder, C, is a little larger than the outside diameter of the hollow rod, A, on which it is to slide.

FIG. 2.

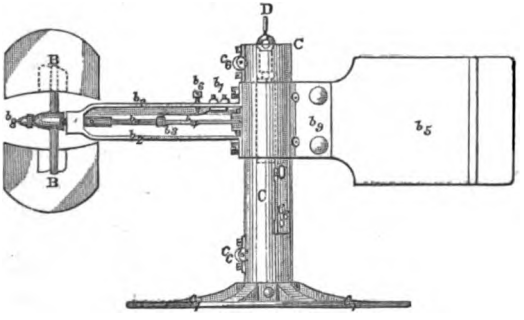


FIG. 4.

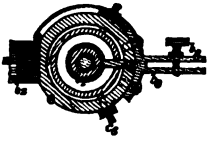


FIG. 5.

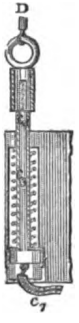
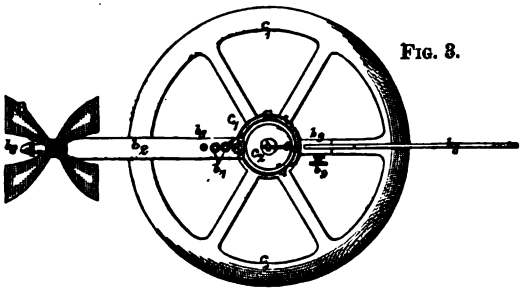


FIG. 3.



The part, c_2, to which the rope is attached is connected with C by an arm which passes through a vertical slit in the hollow rod, A. Thus, the instrument is kept always, if the pipe, A, is properly placed, with its axis normal to the plane of the cross section. The cylinder, C, is also fitted with rollers, c_6 c_8, which render the motion on the fixed rod easy. After the instrument has been placed on the rod or staff, a bracket, E (Fig. 1), with a pulley, e_1, is attached at the top, and the rope is carried over this pulley. The rope, D, is wound on a barrel, F. This barrel is fixed with the frame, f_1, and the pin, f_2, on the arm, G (

7),

Digitized by Google

which is firmly fastened to the hollow rod, A. With the barrel is connected the apparatus, f_3, registering the depth at which the meter is at any moment. The fan, f_4, and gearing, f_5, regulate the rate of rotation of the barrel and permit the adjustment of the speed of the meter in its descent along the rod, A. By the handle, f_6, the meter is again raised. The lever, f_7, and ratchet wheel, f_8 (Fig. 6), arrest the rotation of the barrel. The movement

FIG. 6.

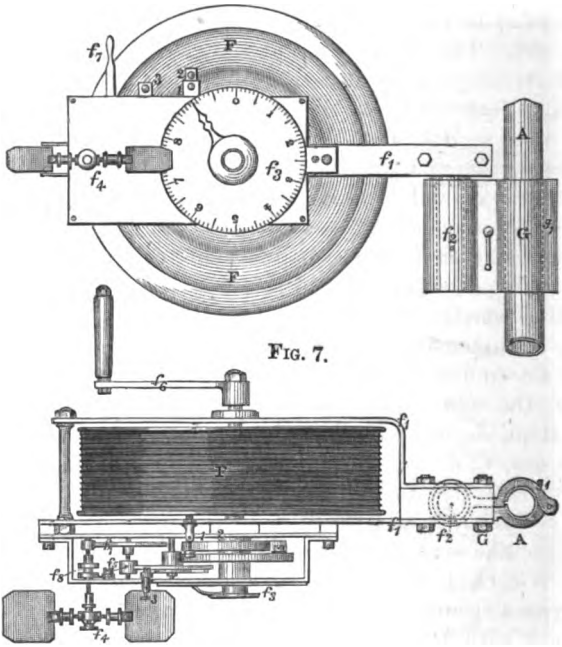


FIG. 7.

begins as soon as the ratchet is lifted by the lever. On the frame of the barrel, F, are fastened the contact screws 1, 2, 3 (Figs. 1, 6 and 7), for attaching the wires of the electric circuit. The screw, 1, is connected with the rope, D, which is a copper-wire rope covered with insulating material. The rope is in electric contact with the shaft of the screw through the spring, c_3 (Fig. 5), because an insulated wire, c_1 (Figs. 5 and 3), connects the lower end of the pin, c_3, and the loop of one of the screws, b_1 (Figs. 2 and 3), which fasten the spring to the brass frame, b_2. The other conductor is the cast-iron pipe, A, which is in contact

Digitized by Google

with the rest of the apparatus through the parts C, G, f_1, f_2, and F (Figs. 6 and 7). These parts are connected with the screw 2 (Figs. 1, 6 and 7). By putting a wire into the loop of screw 3 the depth of the meter below the water-line can be registered electrically. The registering apparatus, H (Fig. 1), has two dials, one marking single revolutions and the other hundreds of revolutions.

If desired, a recording arrangement can be added, the rotations of the meter being marked on a slip of paper in the same way as in a writing telegraph or chronograph. Prof. Harlacher used this arrangement in determining the variation of velocity at a given fixed point. The battery, I, and the clock, or indicator, H, with the rod, A, carrying the meter, are placed on a float, P. The sight vane, K, is fastened to the rod, A, so that it is parallel to the plane of the cross section, and then the axis of the screw is normal to the cross section and parallel to the current. The float is anchored in large rivers and fastened to guide ropes or poles in smaller streams. As soon as the work at one vertical of the cross section is finished, the anchor ropes on one side are slackened and on the other tightened, so as to bring the float into a new position in an easy and a speedy manner. The float must be built so as to be capable of supporting four or five persons.

The determination of the mean velocity at one vertical, by allowing the meter to slide once from the surface of the stream to the bottom, is accomplished thus. The meter, B, and all its connections, C, c_1, &c., are brought to within a few inches of the water surface, the fingers of the electric clock being set to zero. Then the barrel, F, is released by the lever, f_1, Fig. 6. As soon as the axis of the screw touches the water surface a signal is given, the electric clock is brought into the circuit by a spring lever, and begins to count the rotations of the screw. It is necessary to commence with the meter some small distance above the water surface, in order that it may acquire the proper descending velocity previous to the counting of the rotations. In a certain number of seconds the meter descends from M to N (Fig. 1), having at each point in its descent acquired the velocity of rotation corresponding to the velocity of the water at that depth. Dividing the number of revolutions by the number of seconds the rate of rotation corresponding to the mean velocity at that vertical is found. The fact that the disk, c_1 (Figs. 1, 2, and 3), prevents the meter from descending exactly to the bottom entails a small correction. This correction, however, will be more insignificant the larger the difference of the heights MN and NO, that is, the deeper the river

Digitized by Google

in which the observations are made. It is a matter of course that the readings of the instrument at each vertical should be repeated, and the average of the results taken for the true mean velocity. The results of single measurements will not differ much from each other, but the repetition of the readings will give a certainty that all the variations of the velocity at the given vertical are allowed for.

Before using the meter, its constants must be determined in the same manner as with the Woltmann apparatus. A length is marked out in a still-water basin, and the meter is frequently moved through this distance at different speeds. It is essential that the movement of the boat or float on which the meter is fixed should be a uniform one.

The above description of the apparatus will prove that the advantages of this form of meter are of considerable importance. Before the Author was satisfied that the mean velocity in one vertical could be determined by a single observation, in the way described above, he made numerous experiments. The velocity was ascertained by allowing the meter to descend through the water, and also by observing the velocities at equidistant points on the vertical and taking the mean. The results of the two methods differed only in the fourth or fifth decimal place.

The Harlacher Meter may be employed in large and deep rivers. The inventor has used it in the Elbe and Moldau rivers in Bohemia, in the Danube, near Vienna, and in the Seine at Paris. The time required for the measurements is very short. The Author has at various times made observations in the sewers of Leipzig, and in the four small rivers which flow through it, to ascertain the amount of pollution occasioned by sewage. In the year 1878 an officer of the government measured the flow in a mill channel, part of one of these four rivers, with a Woltmann Meter. It took seven hours to record the necessary results. In the Author's investigations on the four rivers, at points lying at an extreme distance of 3,000 yards apart, twelve hours were required, when determining the mean velocity both by allowing the instrument to slide down through the water, and by noting the velocity at every 2 inches of depth. For those observations in which the mean velocity was determined by allowing the meter to descend through the water only, six hours and a half were required for the four rivers, the measurements being repeated at each vertical three to ten times, according to the velocity of the stream. Further, the transport of the float from one cross section to another occupied in all about one hour of the time given above.

Digitized by Google

Prof. Harlacher has described his meter in a treatise[1] which can be recommended to every Engineer interested in these questions. This treatise contains the measurements made in the Danube in 1878. The drawings of the meter are taken from this work.

---

[1] "Die Messungen in der Elbe und Donau und die Hydrometrischen Apparate und Methoden des Verfassers." Von A. H. Harlacher. 4to. Plates. Leipzig, 1881.

Digitized by Google

APPENDIX.

The formula used with the Harlacher meter for determining the velocity of the water v from the observed number of rotations per second n, is [1]—

$$v = \alpha + \beta n,$$

where α and β are constants which must be determined by preliminary experiments with the meter in still water. The meter is towed over a measured distance in still water at different speeds, the speed in each trial being, however, as uniform as possible. The number of rotations of the meter, and the number of seconds occupied in traversing the distance, are observed accurately.

Let m be the sum of the number of seconds occupied in all the trials divided by the number of trials.
v the velocity during any trial.
n the number of rotations in any trial in one second.
$\Sigma(n^2)$ the sum of the squares of the values of n.
Σn^2 the square of the sum of the values of n.
$\Sigma v n$ the sum of the products of the corresponding values of v and n.

Then by the method of least squares—

$$\alpha = \frac{\Sigma n^2 \Sigma v - \Sigma n \Sigma n v}{m \Sigma n^2 - \Sigma n^2}.$$

$$\beta = \frac{m \Sigma n v - \Sigma v \Sigma n}{m \Sigma (n^2) - \Sigma (n^2)}.$$

Example.—Observations for determining the constants of meter No. 1. The meter was moved in still water through a distance of 102·5 metres.

Number of Observations.	Number of Revolutions registered by the Electric Clock.	Time in Seconds.	Velocity in Metres per Second. v.	Revolutions in One Second. n.	n^2.	nv.
1	235	115	0·890	2·043	4·174	1·818
2	232	116	0·890	2·000	4·000	1·780
3	232	113	0·907	2·053	4·215	1·862
4	231	130	0·788	1·776	3·154	1·399
(5)	234	105	0·976	2·228	4·964	2·174
6	236	113	0·907	2·088	4·359	1·893
7	229	121	0·847	1·892	3·579	1·602
8	230	125	0·820	1·824	3·327	1·466
(9)	222	148	0·692	1·500	2·250	1·038
(10)	233	137	0·748	1·700	2·890	1·272

[1] According to Harlacher this formula is sufficiently accurate with his meter for velocities not less than 0·3 metre per second.

Digitized by Google

Rejecting trials Nos. 5, 9, and 10, then

Total time = 833 seconds.

$$m = \frac{833}{7} = 119.$$

$$\Sigma n = 13{\cdot}676; \quad \Sigma v = 6{\cdot}049 \quad \Sigma n^2 = 187{\cdot}03.$$

$$\Sigma (n^2) = 26{\cdot}808 \quad \Sigma n v = 11{\cdot}82.$$

$$\alpha = \frac{187{\cdot}03 \times 6{\cdot}049 - 13{\cdot}676 \times 11{\cdot}82}{119 \times 187{\cdot}03 - 187{\cdot}03} = 0{\cdot}0439.$$

$$\beta = \frac{119 \times 11{\cdot}82 - 6{\cdot}049 \times 13{\cdot}676}{119 \times 26{\cdot}808 - 26{\cdot}808} = 0{\cdot}4188.$$

The following is an example of the use of the meter to determine the discharge of a small stream, the Kleine Luppe, the meter being lowered at uniform speed from the surface to the bottom of the stream.

OBSERVATIONS at VERTICAL No. 3.

Observations.	Registered on Dial of Electric Clock.		Revolutions of Meter.	Time in Seconds.	Revolutions per Second.	
	At Beginning.	At End.				
1	815	871	56	66	0·849	
2	871	941	70	67	0·957	
3	941	1,003	62	66	0·939	
4	1,003	1,068	65	66	0·983	
5	1,068	1,135	67	69	0·971	Mean 0·9275
6	1,135	1,201	76	74	1·027	
7	1,201	1,259	58	71	0·819	
8	1,259	1,325	66	78	0·846	
9	1,325	1,392	67	70	0·957	

Hence $v = 0{\cdot}4323$ metre per second.

OBSERVATIONS at VERTICAL No. 4.

Observations.	Registered on Dial of Electric Clock.		Revolutions of Meter.	Time in Seconds.	Revolutions per Second.	
	At Beginning.	At End.				
1	1,392	1,536	134	92	1·456	
2	1,536	1,690	154	102	1·509	
3	1,680	1,829	139	91	1·529	Mean 1·5492
4	1,829	1,981	152	93	1·634	
5	1,981	2,131	150	92	1·630	
6	2,131	2,271	140	91	1·537	
7	2,271	2,409	138	89	1·550	

Hence $v = 0{\cdot}6427$ metre per second. The mean velocity in the section of the river between verticals 3 and 4 is therefore $\frac{1}{2}(0{\cdot}4323 + 0{\cdot}6427) = 0{\cdot}5375$.

Digitized by Google

These observations were taken in 26½ minutes, including the time required to shift the float and meter from one vertical to the other.

In the Danube Prof. Harlacher has used the meter in a depth of 8 metres (26¼ feet), and the water there had the great velocity of 3 metres (9 feet 10 inches). The hollow rod used in this case had a diameter of 50 millimetres (1·92 inch). Prof. Harlacher thinks that if the velocity does not exceed 2 metres (6·56 feet), a rod of that size would be strong enough for depths of 20 metres (65·6 feet). The only problem to solve would be to connect the pieces of which such a rod must consist.

Prof. Harlacher has investigated the variations of velocity in a stream by placing five meters at equal distances apart on the same rod. The meters recorded every revolution independently by means of an electric chronograph.

Digitized by Google

(*Paper No. 1840.*)

"A Study of the Problem of Aerial Navigation, as affected by Recent Mechanical Improvements."

By WILLIAM POLE, F.R.S., M. Inst. C.E.

IN a few remarks appended by the Author[1] of this Paper to the discussion on Mr. Thornycroft's communication "On Torpedo-boats and Light Yachts for High-speed Navigation," he ventured to express the view that the remarkable reduction lately effected in the weight of power-producing apparatus, might have an important influence on the solution of the problem of the navigation of the air. He considers it may not be out of place, as a matter of mechanical investigation, that he should offer to the Institution some account of the facts and reasonings on which this view is founded.

The serious discussion of the possibility of commanding locomotion at will through the air is often avoided from the fear of encountering popular ridicule. But the engineer and the student of mechanical science will know that there is nothing unreasonable or inconsistent with mechanical principles in the idea. The problem of producing motion in a given direction through the air is analogous with that of producing motion in a given direction through the water, and is subject to the same general laws. Hence, as the latter problem has been long ago practically solved, one may fairly inquire how far the former one is likely to admit of solution also.

The complete form of the problem of aerial navigation is, of course, that of flying, and the study of the mechanical conditions of that wonderful process is one of the most interesting offered by nature. But as hitherto no approach has been made to any artificial imitation of it, its discussion would be out of place here; and it is proposed to confine attention to a modified form of the problem, in which one of its chief difficulties has been removed. The invention of the balloon, about a century ago,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxvi., p. 174.

Digitized by Google

overcame the great obstacle to aerial operations caused by the action of gravity, and so immensely simplified the conditions to be studied, as to bring the problem much more within the reach of practical skill. It is therefore to aerial navigation by means of balloons that this Paper applies.

The analogy between motion in water and in air has already been pointed out; and it becomes closer when the aeronautic apparatus has the power of floating. Now it is known by every-day experience that if, in the case of a boat or steamer, an action can be applied, by a force within the vessel, against the surrounding water, the reaction will propel the floating body in an opposite direction: and similarly if a force carried in a balloon can be made to act against the surrounding air, it is equally certain that a propulsion in the opposite direction will be given to the balloon.

And it follows that if motion can be given through the air, there will also be a *steering* power; for the well-known contrivance of the rudder will be as effective, if properly proportioned, in the rarer as in the denser medium. Hence a balloon thus constituted will be capable of navigating the air in any required direction, or will be (to borrow a very appropriate term from the French) a *dirigible* balloon.

The problem, then, in regard to such a balloon is, to ascertain by what means an action can be caused against the air by some force within the balloon itself; and to investigate the result of this force in effecting the propulsion.

The discussion of this problem now to be offered is of no speculative character, and contemplates no novelty of invention. It will be based entirely on existing facts, and on trials made on a full practical scale, which will furnish the data for reasoning on the future possibilities of aerial navigation. Hence it is proposed (I.) To state what has been done; (II.) To infer from this what may be done; and (III.) To offer some considerations on the subject of a practical character.

What has been done.

It is worthy of record that the analogy between water and air navigation was perceived by a great mind, at the time the balloon was invented. As early as December 1783, *i.e.* only six months after Montgolfier's first public experiments, Lavoisier, the most eminent chemist and physicist of the day, gave before the French

Digitized by Google

Academy[1] an admirable *résumé* of the conditions which should be fulfilled in aerostatic machines, and which are as perfectly applicable now as they were then. In studying the subject he saw clearly that, by reaction against the air, an independent motion might be given to the balloon, and might be made use of to modify the direction impressed upon it by the wind, or in other words to render it dirigible. Accordingly, the last of his conditions ran thus:—

> Finally, by employing the force of men, it appears certain that it will be possible to cause the direction of the balloon to vary from the direction of the wind, under an angle of several degrees.

Lavoisier's idea was discussed by the Montgolfiers, who proposed to adapt oars to their balloons; and other early aeronauts from time to time made experiments in the same direction; but none of these efforts were successful. Hence the great expectations which had been raised as to the new power of locomotion gradually dwindled away, and an opinion set in that aerial navigation by balloons was, in the nature of things, impossible. This view prevails widely at the present day, and it is not unusual to see the most preposterous and unmechanical notions gravely put forward in support of it. But the explanation of the failure of the early attempts is obvious enough; it lies simply in the difficulty of finding any adequate means of applying the power. Oars were unsuitable with total immersion, and no mechanical ingenuity could imitate the beautiful action of a fish's fin, or a bird's wing. To make the balloon a manageable locomotive agent required a degree of advancement in mechanical practice which has only been attained in very recent times.

It was not till half a century after the invention of balloons that the introduction of the screw propeller[2] removed the first difficulty, by providing an efficient apparatus for acting against the air. This apparatus was at once of the simplest character, suitable for total immersion, easily worked, and capable of applying, in the most effectual way, almost any amount of power that could be desired. After its introduction the practicability of aerial navigation could be no longer doubtful.

---

[1] Reprinted in the "Comptes Rendus," vol. lxxi., p. 608.

[2] The screw had often been proposed, at earlier times, as a mode of propelling ships, but it was not believed in till the date of Mr. F. P. Smith's successful trial in November 1836. The "Archimedes," the first large screw steamer, put to sea on the 15th May, 1839.

Digitized by Google

The first person who made a serious attempt to utilise the screw for balloons was a young French engineer whose name has since become famous in the engineering world on other grounds, M. Henry Giffard, the inventor of the "Injector," one of the most elegant contrivances ever introduced into engineering. It was about 1850 that M. Giffard turned his attention to the matter, but he found there was much to be done before the experiment could be carried out with any chance of success. In the first place he saw that the ordinary form of the balloon, namely globular, was very unsuitable when lateral motion through the air had to be effected; the well known analogy of vessels for water-navigation demanding that the shape should be elongated, diminishing at the bow and stern. To complete the analogy, it was also necessary that this elongated vessel should have a keel and a rudder. As a power to work his screw, he took the bold step of using a steam engine, adopting, however, ample precautions against fire, among which was the ingenious expedient of turning the funnel downwards, and producing the draft by a steam blast, as in the railway locomotive.

His balloon was 12 metres diameter and 44 metres long. The car was suspended by a net in the usual way, and there was a large triangular sail attached to the stern, serving as keel and rudder combined. The steam engine was 3 HP., and worked a two-bladed screw 3·4 metres diameter, which could be given one hundred and ten turns per minute. The general appearance of the balloon will be seen from the accompanying figures.

M. Giffard ascended from Paris on the 24th September, 1852. Having arrived at a convenient height, he started his engine, and the independent motion produced thereby became at once evident by the prompt obedience of the balloon to the action of the rudder. It was "under way," and could be steered like a ship at sea. He found that the screw gave an independent velocity through the air of from 2 to 3 metres a second, or $4\frac{1}{2}$ to $6\frac{3}{4}$ miles an hour.[1]

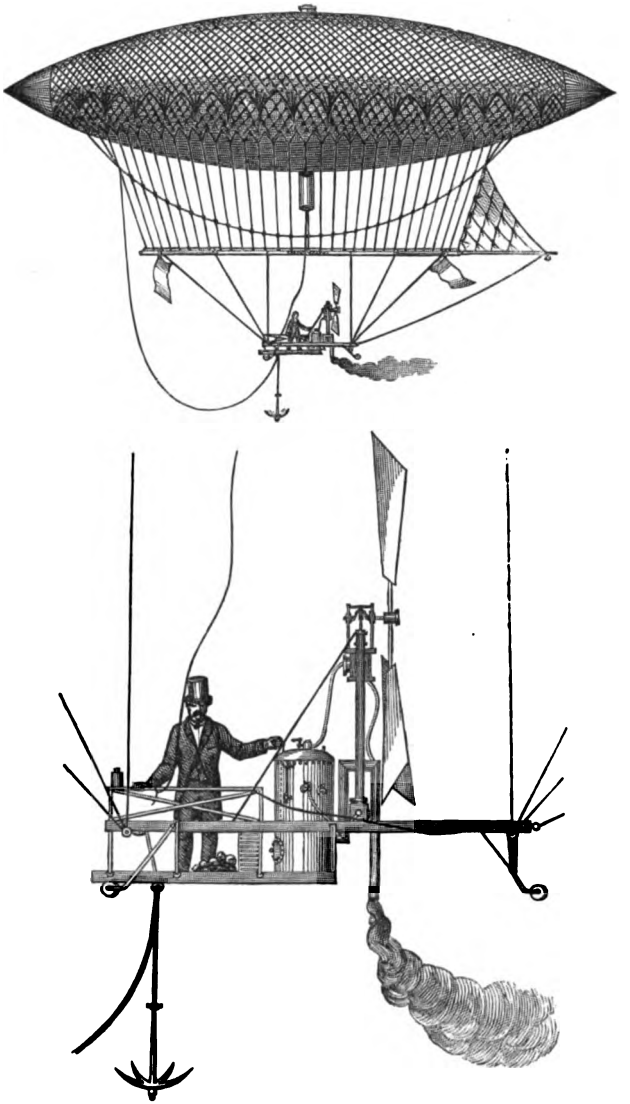
He intended to continue his experiments, but he found that, in order to get the best results, many improvements were necessary which would take time. His attention was then occupied on

[1] A description of the balloon and its voyage was published in "La Presse" of the 25th September, and was reprinted eighteen years later in the "Comptes Rendus," vol. lxxi., p. 683. See also "Les Ballons Dirigeables," by Gaston Tissandier. Paris. 1872; from which the figures are borrowed.

Digitized by Google

other mechanical subjects, but in 1867 and 1868 he had occasion to construct two large captive balloons, in which were perfected

M. H. Giffard's Dirigible Balloon, 1852.



some of the improvements he had in contemplation, in particular the impermeability of the envelope, a more mechanical construction

Digitized by Google

of the valves, and a better and cheaper mode of preparing pure hydrogen.

During the siege of Paris in 1870, balloons were used to a large extent, as is matter of history, in order to get despatches out of the city. They were, unfortunately, not available for communication in the other direction; but it occurred to the authorities that if they could be given even a slight independent motion they might be made so, and this led to another experiment under the auspices of M. Dupuy de Lôme, the eminent naval architect to the French Government. He constructed a balloon, of an elongated shape, 14·84 metres diameter and 36·12 metres long. The car carried a screw-propeller of two sails, 9 metres diameter, intended to be turned by four men, a relay-gang being also taken up to relieve them. The experiment was interrupted by the Communist insurrection, but it was completed afterwards, and the ascent was made on the 2nd February, 1872. Careful observations were taken during the voyage, and they established beyond a doubt the efficiency of the propelling apparatus in giving a velocity to the balloon independent of the wind. It was found that when all eight men were working together at the screw, giving it 27½ revolutions per minute, an independent velocity was obtained of 2·82 metres per second, or about 6·3 miles per hour.

As a matter of fact M. de Lôme did not accomplish much beyond what M. Giffard had done many years earlier; but his work has a peculiar merit of its own, namely the full and able manner in which, applying to the subject his great knowledge of marine navigation, he has discussed all the elements of the problem. And by the lucid detailed descriptions and explanations he has put on record, both of his calculations and of his experimental results, he has given a firm basis for the extension of the principle to a wider range.[1]

The importance of these two trials, as bearing on the practicability of aerial navigation, cannot be denied; but doubts have been expressed whether the results given can be implicitly accepted. It is said (1) that the determination of the independent speed must be so difficult as to be liable to error; (2) that the results of the two trials, with such different amounts of power, are very discordant, and (3) that had such marvellous accounts been credited at the time they must have been followed up. In

[1] These particulars will be found in several elaborate articles communicated from time to time to the Academy of Sciences, and published in the "Comptes Rendus," vols. lxxi. and lxxiv.

Digitized by Google

M. Giffard's case, there is, it is true, only the unsupported statement of an engineer of known reputation and great skill; but with regard to M. de Lôme's trial, a reference to the "Comptes Rendus" will show abundant evidence of the correctness of his statements. He pre-arranged with great care the modes of observation; he was accompanied and assisted by several other persons, and it is incredible that the full detailed particulars communicated to such a body as the French Academy, by a man of such high position, can have been otherwise than trustworthy. The discrepancy between the two trials will be explained elsewhere; and the apparent neglect of the experiment is easily accounted for by the circumstances of the time, and the want of any sufficient inducement for its renewal. The best answer however to these objections is, that the results are perfectly consistent with mechanical principles, as will now be shown.

What may be done.

Under this head it is proposed to investigate generally, as a mechanical problem, the capabilities of balloons for aerial navigation.

Assuming that a suitable elongated shape, of circular section, has been determined on, let the maximum diameter be represented by d, and the length by l. Then the contents will be proportional to $d^2 l$, and the *ascending force* of the gas may be expressed by $A d^2 l$; where A is a coefficient depending on the shape of the vessel, and on the specific gravity of the gas compared with that of the surrounding air.

The *weight* of the envelope, assuming the material the same, will vary as the maximum diameter multiplied by the length; and for the sake of simplicity, one may, probably without much error, apply the same proportion to the other parts of the structure generally, apart from the motive power. Therefore, using another coefficient to be obtained from experience, the weight of the structure may be expressed by $B d l$.

Hence the *available ascending power* $= A d^2 l - B d l$, or $= (A d - B) d l$.

Now this available ascending power has to support the weight of

1. The motor.
2. The necessary stores, such as fuel, water, &c.
3. The cargo.

The proportionate weight to be allotted to each of these respectively will depend on various considerations which it is impossible to reduce to any general rule. For the present purpose

Digitized by Google

attention may be confined to the first item, the motor; and there may be allotted to it a proportion of the whole available weight represented by r; so that the weight of the engine, or whatever the motor may be, will be $= r\,(A\,d - B)\,dl$.

If then S represent the weight of the motor for each (useful) HP., then—

$$\text{Useful HP. of motor carried} = \frac{r}{S}(A\,d - B)\,dl \quad . \quad . \quad \text{(I.)}$$

The next question is how the power of the motor is to be expended.

The first element in the calculation is the resistance of the balloon to motion through the air. This is a point of great importance, and it will be necessary to treat it more at length hereafter. For the present, it may be safely assumed, in accordance with the analogy of bodies moving in fluids generally, to vary, for moderate speeds, as the square of the velocity, and it may be represented by $X\,v^2$, where X is a coefficient depending on the dimensions and form of the balloon.

The HP. necessary to propel the balloon at a given velocity v, will be equal to the resistance multiplied into the velocity, and divided by a certain constant number dependent on the units in which the quantities are taken. Call this H. (For resistance in lbs. and velocities in feet per minute, H = 33,000. For velocities in miles per hour, H = 375; in feet per second H = 550.)

Hence—

$$\text{HP.} = \frac{X\,v^3}{H},$$

which represents the power necessary to propel the balloon through the air.

The next question is as to the *efficiency of the propeller*. This has been often investigated for water navigation. Rankine, in his elaborate article on "Propellers,"[1] gives the efficiency of the screw of the "Warrior" = 77½ per cent. Mr. Isherwood[2] makes that of two small boats by Maudslay and Penn = 65½ and 71½ respectively. Mr. Froude[3] reduces it, for high speed working, to 57½, but this great loss is attributed to causes which would hardly apply to air navigation. M. de Lôme estimated the efficiency at 72½ per cent., taking a probable "slip ratio" of 21½ per cent.

[1] Trans. Inst. Naval Architects, 1865.
[2] Article by Mr. Pendred. *Ibid.*, 1876.
[3] *Ibid.*, 1876.

Digitized by Google

But, as will be hereafter shown, the actual slip in his trial was a little greater, and therefore the efficiency may be put down at 70 per cent., which is fairly borne out by nautical experience. According to this, for every 7 HP. directly expended in propelling the vessel, 10 HP. must be applied to the screw shaft, and the equation becomes—

$$\text{Useful HP. of motor carried} = \frac{10\,X\,v^3}{7\,H} \quad . \quad . \quad . \quad . \quad \text{(II.)}$$

Equating now (I.) and (II.) and reducing—

$$v^3 = \frac{7\,r\,H}{10\,S\,X}(A\,d - B)\,d\,l.$$

If all dimensions are expressed in feet, weights and pressures in lbs., and velocities in feet per second, then H = 550, and

$$v^3 = \frac{385\,r}{S\,X}(A\,d - B)\,d\,l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

An equation which expresses, in a compact form, the relations between the chief elements that enter into the problem.

The next step is to obtain the values of the important coefficients A, B, and X.

Ascending power.—Supposing the balloon to be filled with pure hydrogen the levity of one cubic foot, at 32° Fahrenheit, and under one atmosphere, will be = 0·0751 lb. The volume of the balloon, according to M. de Lôme's proportions, was about $0{\cdot}434\,d^2\,l$ cubic feet, so that on this supposition the floating power would be $= 0{\cdot}0327\,d^2\,l$. In fact the floating power was $= 0{\cdot}03\,d^2\,l$. The coefficient may therefore be taken at its lower value, *i.e.*

$$A = 0{\cdot}03.$$

Weight of the structure.—There is no means of calculating this *à priori*, as it comprehends such a variety of items, dependent entirely on practical considerations. The coefficient must therefore be taken from examples on record. In M. de Lôme's balloon the weight was 3885 lbs. $= 0{\cdot}673\,d\,l$; in M. Giffard's it appears to have been less. The former is the more authoritative, therefore

$$B = 0{\cdot}673.$$

Resistance of the balloon to motion through the air.—This is the most important element of the whole investigation, and is at the

Digitized by Google

same time the most difficult to determine, from the scarcity of experimental data on a large scale. It is, however, some palliation of the difficulty to know that the resistance of vessels propelled in water is also a quantity liable to much variation and uncertainty, notwithstanding the large amount of experience gained in water navigation. The proper course to adopt here is to apply mechanical analogies as carefully as possible.

The resistance of ships to motion through water may be estimated according to either of three elements of their dimensions:—(1) The area of immersed midship section; or (2) the skin friction; or (3) the cubic displacement. It will be advisable to apply each of these to the case of the balloon, and see how they correspond.

(1) *By the midship area.*—This plan was adopted by M. de Lôme, and the following is a *résumé* of the way he treated it. He proposed in the first instance to get a velocity of 8 kilometres (4·97 miles) per hour. He took the resistance to a plane surface passing perpendicularly through the air at this speed at 0·665 kilogramme per square metre. But, as is well known, this is reduced in a very large proportion by the pointed form. The elaborate modern investigations of Mr. Froude have shown that, theoretically, the head resistance may be almost annihilated if the most suitable form is adopted; and M. de Lôme gives, as a matter of practical experience, the fact of a reduction, in well-formed steamers, to an amount varying between $\frac{1}{40}$ and $\frac{1}{80}$ of the resistance due to the midship section. For his aerial structure, however, he was content to allow a double proportional resistance, taking the coefficient for the balloon at $\frac{1}{20}$. For the car, accessories, and suspending apparatus he took a coefficient of $\frac{1}{2}$. This brought out the resistance as follows:—

	Square metres.	Kil.
Balloon	$154 \times 0{\cdot}665 \times \frac{1}{20}$	$= 5{\cdot}12$
Car, &c.	$14 \times 0{\cdot}665 \times \frac{1}{2}$	$= 4{\cdot}68$
	Total resistance	$= 9{\cdot}80$

$$= 21{\cdot}6 \text{ lbs.}$$

This would be the quantity $X v^2$ for a velocity of 7·3 feet per second, and a midship diameter of 48·67 feet. From which it follows that the resistance, estimated according to this method,

$$= 0{\cdot}000171\ d^2 v^2.$$

The calculation may be checked in another way. According to the data of wind pressures usually adopted by English engineers,

Digitized by Google

namely, those given by Smeaton to the Royal Society, in his Paper on Windmills, the pressure on each square foot of flat surface $= \frac{1}{237} v^2$, where v is in feet per second.

The area of the midship section will be $= \frac{\pi}{4} d^2$; and that of the car, &c., may be taken at $\frac{1}{11}$ of this. Hence, allowing the same reductions for the form as M. de Lôme did, the total resistance—

$$= \left(\frac{\pi}{80} d^2 + \frac{\pi}{88} d^2\right) \times \frac{v^2}{437}$$

$$= 0{\cdot}000172\ d^2 v^2,$$

agreeing almost identically with M. de Lôme's estimation.

(2) *By the skin friction.* — This is a mode which has been sanctioned by recent scientific investigations. Professor Rankine has stated[1] that if W = wetted surface of a ship in square feet, the resistance in lbs. may be taken as $= \frac{\text{C W (speed in knots)}^2}{100}$ where C is a constant something greater than unity, whose exact value depends on the lines of the vessel. For the "Warrior," 9000 tons, he found it $= 1{\cdot}275$; for the "Fairy," 168 tons $= 1{\cdot}124$. Taking the higher value and putting v = the speed in feet per second, the resistance will be

$$= \frac{W v^2}{224}.$$

Now if air be substituted for sea water the resistance will be diminished in the ratio of the densities, *i.e.* 793 to 1; and further, the surface of the balloon exposed to the friction of the surrounding fluid may be taken as proportionate to $d l$: in M. de Lôme's structure it was about $= 2{\cdot}3\ d l$. Hence on this mode of estimation, the resistance for the balloon, taken on the same coefficient as the "Warrior," will be

$$= \frac{2{\cdot}3\ d l v^2}{224 \times 793}$$

$$= 0{\cdot}00001295\ d l v^2.$$

Adopting then Mr. de Lôme's allowance, for the balloon, of double the proportional resistance for a good ship, and adding, as he also does, 88 per cent. for the car, &c., the resistance comes out according to this mode of estimation

$$= 0{\cdot}0000477\ d l v^2.$$

(3) *By the displacement.*—This mode combines both the former

[1] Trans. Inst. Naval Architects, 1864 and 1865.

Digitized by Google

elements of midship section and skin surface. If D = displacement of a vessel in tons, and v her speed in knots per hour, then the rule given is [1]—

$$\text{Resistance in lbs.} = C \times v^2 D^{\frac{2}{3}},$$

where C is a coefficient varying from 0·8 to 1·5, according to the form and condition of the ship. Taking C = 1 for a moderately good example, and changing D to cubic feet, and v to feet per second, the resistance is

$$= \frac{v^2 D^{\frac{2}{3}}}{30 \cdot 5}.$$

The displacement of the balloon has been given already as $= 0 \cdot 434\ d^2 l$, and proportioning for the densities of air and sea water, the resistance becomes

$$= 0 \cdot 0000238\ d^{\frac{4}{3}} l^{\frac{2}{3}}.$$

Increasing as before, and adding for the car, &c., it is

$$= 0 \cdot 0000886\ (d^2 l)^{\frac{2}{3}} v^2.$$

These three values of the resistance may be compared in the case of any balloon where the proportion of length to diameter is given. In M. de Lôme's balloon, for example, $l = 2 \cdot 43\ d$. Substituting this and reducing, the resistance becomes, when estimated

By midship section	$= 0 \cdot 000172\ d^2 v^2$;
„ skin friction	$= 0 \cdot 000116\ d^2 v^2$;
„ cubic displacement	$= 0 \cdot 000160\ d^2 v^2$.

The estimation by skin friction is the smallest, for the obvious reason that in this structure the proportion of length to transverse dimensions is so much less than is usual in ships. The general comparison, however, shows that the estimate by midship area adopted by M. de Lôme, is fairly corroborated by other methods quite independent, and it may therefore be safely taken as representing the resistance.

It is now possible to apply the formulæ to M. de Lôme's case, and see how the results correspond with those of experiment. The values of S and r must, however, be first obtained from his data.

[1] Rankine, "Rules and Tables," p. 274.

Digitized by Google

The motive power he used was eight men, and he states that, when they were all working together, they produced $\frac{8}{10}$ of a horse power. The men weighed 1325 lbs., which gives—

$$S = 1656.$$

And as his total available ascending power was 2,046 kilograms = 4515 lbs., the proportion r allotted to his motor was $\frac{1325}{4515}$ = 0·3 nearly.

Returning now to equation III., and making $l = 2{\cdot}43\,d$, and $X = 0{\cdot}000172\,d^2$, it becomes—

$$v^3 = 440{,}000\,\frac{r}{S}\,(A\,d - B).$$

Wherefore, inserting the values of A, B, r, and S, previously given, the velocity comes out = 9·2 feet per second, or

$$= 6{\cdot}25 \text{ miles an hour,}$$

which is almost identical with the speed actually obtained on the trial.

This agreement of the calculated and the observed velocities shows, in the first place, that the result obtained by M. de Lôme is in perfect accordance with what might be expected according to ordinary mechanical laws; and secondly, it gives a practical warrant for the more extended application of the reasoning. It is clear that since the power exerted is known, the estimate made of the resistance must hold good, at any rate for moderate velocities; and although there are no experimental data for higher speeds and greater power, yet the analogy of experience in marine engineering will justify the wider application of the rules, if the principles on which they are constructed are sound.

It is therefore proposed to examine what might be expected to be the performances of dirigible balloons, if, in the provision of their power, due advantage were taken of the most recent improvements in mechanical engineering.

It will be evident that the kind of power used by M. de Lôme was exceedingly disadvantageous, by reason of its great weight. He fully admitted this, but his object was a limited one, and, under the circumstances, he took, no doubt, the wisest mode of attaining it; for an independent velocity of a few miles an hour would, by taking proper advantage of the wind, certainly have sufficed to enable balloons to enter the city. For more extended applications,

Digitized by Google

however, human power is out of the question, and it is necessary to go back to M. Giffard's plan of using steam, with which, for this purpose, no other kind of motor at present in use could compete.

But although steam power is lighter than that of men, still down to a late period it has been too heavy to be of any real utility in a case of this kind, where the carrying capability is so limited. According to the usual practice with engines used for steam navigation, it may be reckoned that the motor employed has weighed 4 to 5 cwt. per HP., which is also about the weight of small fixed engines in the ordinary market at the present day. At this rate the amount of power which could be carried in a balloon would be so small as not to do much towards the successful solution of the problem of aerial navigation.

But recent improvements have much changed matters in this respect; for in cases where economy of weight has been desirable, the skill of engineers has succeeded in effecting it to a very remarkable extent. In the modern locomotive, for example, much has been done to increase the power that can be developed by an engine of a given weight, and if those parts are excluded which properly belong to the vehicle, and not to the engine, the weight would probably come out not more than about 1 cwt. per HP.

But even this has been much improved upon within the last few years, as will be seen by the Paper by Mr. Thornycroft, already referred to. It shows that in the arrangements of power for the light boats there described, the Author has succeeded in bringing the weight of the whole propelling machinery down to 43·5 lbs. per indicated HP.; which, omitting the screw and its long shafting and bearings, would probably give not much more than 40 lbs. for the motor alone. In the discussion which followed the reading of the Paper, opinions of high authority were expressed that further reductions were possible, particularly in regard to the boiler; but the figure already obtained will suffice for the present object.

It is, however, necessary, in order to make this correspond with the terms of the foregoing formulæ, to transform it into the weight per *useful* HP. The loss between the power indicated in the cylinders and that available at the end of the crank-shaft varies of course in different engines, but it is usually reckoned from 15 to 25 per cent. Professor Rankine estimated the loss on the engines of the "Warrior" at 22½ per cent.; Mr. Isherwood made that of Maudslay's and Penn's engines 13 and 14½ per cent. respectively. Mr. Froude estimated it higher, namely 33·3 per cent.; of which

Digitized by Google

7·1 per cent. was due to the several pumps. In engines of the light and simple character of those here contemplated, without any air, bilge, or condensation pumps, probably 20 per cent. allowance would be ample; *i.e.* for every 4 HP. applied to the screw shaft, 5 HP. must be indicated in the cylinders. This brings the weight to something over 50 lbs. per useful HP.

But there is another point to consider. If steam power is used, the weight of a store of fuel and water must be also taken into account in the burden to be carried. The consumption of fuel for the lightest engines is given by Mr. Thornycroft at a little under 4 lbs. per indicated HP. per hour; probably some kind of liquid hydro-carbon might be most advantageous for this purpose, and might also lead to a reduction in the weight to be carried.

The water, however, is at first sight a more formidable consideration, the quantity necessary being from 25 to 28 lbs. per HP. per hour. Such a large addition would, a few years ago, have rendered steam-ballooning almost impracticable; but fortunately here again recent improvements have come in aid. The water used in steam engines is not, like the fuel, decomposed and dissipated; it is only changed in form, and can be reproduced by cooling. M. Giffard saw this, and with the skill of an accomplished practical engineer he proposed to introduce a system of air condensation. The Abbé Moigno gave, in the "Mondes" of 15 Oct., 1863, an account of various improvements which M. Giffard had then on hand, and the following passage refers to this point:—

"The provision of water which it is possible to carry in the air being necessarily very limited, it is desirable to use the same water, by condensing the steam after it has produced its mechanical effect. This new improvement has been carried out as rapidly as the former ones; any of our readers may, whenever they please, see, in the Avenue de Suffren, No. 40, suspended to the ceiling of the workshop, a series of flat tubes offering a large surface, which condense the steam of a 10-horse engine."

The air-condenser has been used in this country by Mr. Perkins and Mr. Cradock, and it has within the last year or two been successfully applied by Messrs. Kitson and Co. to tram-cars running in the streets of Leeds. It is therefore no longer a mere theoretical possibility, but an accomplished fact in steam-engineering. From data the Author has obtained it appears that with a moderate surface about three-fourths of the water may be recovered, and that a condenser adapted to this purpose may be estimated to weigh about 20 lbs. for each useful HP. of the engine.

From these data the weight may now be made up more accu-

Digitized by Google

rately. The weight of the engine, with the condenser, may be taken at 75 lbs. per useful HP., *i.e.*

$$S = 75,$$

instead of 1656, as in M. de Lôme's balloon.

The store of fuel and water necessary to be carried may be estimated, according to present data, at from 10 to 12 lbs. per HP. per hour; but there is little doubt that this quantity, as well as the weight of the engine, could be reduced if the necessity for doing so should arise.

In proceeding now to apply the formulæ to new cases, it is necessary to determine a proportion of length to diameter. This in M. de Lôme's case was made 2·43; in M. Giffard's balloon, it was 3·66. There can be no doubt of the advantage of length in diminishing the proportion of resistance to capacity, and in giving better steering properties; and even M. Giffard's proportion (which he found answer perfectly well), is very small when compared with those common in water navigation. In the following calculations, therefore, the proportion $\frac{l}{d} = 3\frac{3}{5}$ will be adopted.

This will lead to a new comparison of the estimated resistance, as determined by different methods. By substituting the value of l in terms of d in the various resistance equations, it will be found that the following values appear—

By midship section $= 0{\cdot}000172\ d^2 v^2$;
„ skin friction $= 0{\cdot}000175\ d^2 v^2$;
„ cubic displacement $= 0{\cdot}000211\ d^2 v^2$.

Here, it will be observed, the effect of the increased length is to bring out higher values of the resistance according to the two latter modes of estimation. On this ground it will be safer to adopt them in preference to the former; and in the absence of any special experience as to which of the two is the more applicable, the mean may be taken, *i.e.*

$$X = 0{\cdot}000193\ d^2.$$

It is further necessary to determine r, the proportion of ascending power to be devoted to the motor, and this may be conveniently made one-third. A sixth may then be added for a store of fuel and water, which would suffice to keep up the maximum power for three or four hours, but would last much longer under ordinary working, when advantage would be taken, to the

Digitized by Google

utmost extent possible, of the direction of the wind. (This store of consumable material might take the place of the ballast used in ordinary aerostation.) The remainder of the net ascending power, one-half, would be available for cargo.

It may be advisable to add to the constant B, to allow for some increased weight that may probably be necessary to meet an increase of power and speed. Instead of 0·673, let

$$B = 0{\cdot}72,$$

an increase of 7 per cent. on the whole weight of the structure.

Substituting the above values in equation III., it becomes, in round numbers, for the maximum possible speed through the air—

$$\left.\begin{aligned} v^3 \text{ in feet per second} &= 975\,(d - 24) \quad . \quad . \quad . \\ v^3 \text{ in miles per hour} &= 313\,(d - 24) \quad . \quad . \quad . \end{aligned}\right\} \quad \text{(IV.)}$$

It remains to say something of the necessary size and velocity of the screw-propeller. This instrument must, no doubt, be large, owing to the comparative rarity of the medium against which it is to act; but an idea may be formed of its proportions according to the analogy of water navigation.

In regard to the diameter, the usual rule is to make the area of the screw circle proportional to that of the immersed midship section. M. de Lôme states that the most favourable proportion, for good ships, is $\frac{1}{4}$; but considering the increased coefficient of resistance which he had allowed for his vessel, he fixed the diameter of his screw at 9 metres, which gave a proportion to the area of $\frac{63\frac{1}{2}}{168}$ or $\frac{1}{2{\cdot}65}$. In English steamers,[1] the proportion varies a great deal, but it may generally be taken as from $\frac{1}{2{\cdot}5}$ to $\frac{1}{3{\cdot}5}$. M. de Lôme's screw was very nearly $\frac{3}{5}$ the maximum diameter of the balloon, and, in default of any experience to the contrary, this proportion may be retained.

In order to calculate the velocity of rotation, it is necessary to estimate the amount of slip. In M. de Lôme's trial, the pitch of the screw was 8 metres, the number of revolutions $27\frac{1}{2}$ per minute, and the speed of the balloon 169·2 metres per minute. Hence the advance of the vessel for each revolution was 6·15 metres, giving a "slip ratio" of $\frac{1{\cdot}85}{8}$, or about 23 per cent.

[1] See data for a very large number of screw ships in "Bourne on the Screw Propeller." 4to. London, 1867.

Digitized by Google

M. de Lôme's pitch was $\frac{2}{3}$ the diameter, but this is unusually fine, the general ratio varying from 1 to 1·5. With steam power, no doubt the pitch might be advantageously increased, but in the absence of experience it may not be advisable to depart too widely from what has been done, and the ratio may be put = 1. M. de Lôme originally proposed this pitch, and why it was reduced he does not explain.

Calculating on the above slip and pitch, if n = revolutions per minute—

$$n = \frac{78\,v}{\text{diameter of screw}},$$

or, reverting to equation IV.—

$$n = 1{,}160\,\frac{(d-24)^{\frac{1}{3}}}{d},$$

which will give the number of revolutions for the maximum speed of any diameter of balloon on the data before named.

Returning to equation IV., the expression shows that a certain magnitude of balloon is necessary to obtain any power of navigation, and that the capability will increase with the diameter. Some different sizes may be calculated in order to illustrate the application of the formulæ, and the results are shown in the following Table.

DIRIGIBLE BALLOONS.

As calculated from data in accordance with the actual trials of Messrs. Giffard and Dupuy de Lôme, combined with the results of the most recent improvements in steam motors.

Maximum diameter	Feet. 30	Feet. 40	Feet. 50	Feet. 75	Feet. 100
Length	110	147	183	275	367
	lbs.	lbs.	lbs.	lbs.	lbs.
Total ascending force	2,970	7,040	13,750	46,400	110,000
Weight of structure	2,370	4,220	6,600	14,850	26,400
Available ascending force	600	2,820	7,150	31,550	83,600
HP. of motor	3	12	32	140	370
Weight disposable for cargo, after allowing for fuel and water	Cwt. 2½	Cwt. 12½	Cwt. 32	Tons. 7	Tons. 18½
Maximum speed through the air . . . miles per hour	12	17	20	25	29
Diameter of screw . . in feet	18	24	30	45	60
Revolutions per minute for maximum speed	76	81	77	64	55

Digitized by Google

The smallest size of balloon that would be of any use would be about 30 feet diameter. This would carry an engine of about 3 HP., giving a maximum speed of 12 miles an hour. The weight available for cargo would be, however, only about sufficient for one person.

Next take 40 feet diameter, the size of M. Giffard's balloon. This would carry 12 HP., would attain 17 miles an hour, and would carry 12½ cwt. of cargo. M. Giffard's engine was only 3 HP., but his balloon was inflated with common coal-gas instead of hydrogen, and was therefore deficient in ascending force. The power he had ought to have produced a speed of 10 miles an hour; the reason his result fell so much short of this was the small size of the screw, which was only about one-fifth the proper area, and was therefore quite unable to utilise beneficially the power employed. It is well known, in water navigation, that the loss by slip increases largely when the screw is unduly reduced in size.

The next example is about the size of M. de Lôme's balloon, 50 feet diameter, and the calculation shows what it would have done had he used more favourable proportions, and availed himself of the modern steam power. He could, at this rate, have carried an engine of 32 HP., which would have turned his screw three times as fast, and would have given him, with the higher pitch, a speed of 20 miles an hour.

By increasing the diameter to 75 feet, the balloon would have a velocity of 25 miles per hour. Even 100 feet diameter would not be an unreasonable magnitude, and this, keeping the same proportion of power to weight, would give a speed through the air approaching 30 miles an hour, and would have 18½ tons disposable for cargo.

These are no doubt startling results, but they arise legitimately from the data now in existence, and it will be seen that their significance, in giving a new aspect to the problem of aerial navigation, is largely due to the mechanical improvements effected in quite recent times. Before the invention of the screw propeller, there were no feasible means whatever of attacking the problem; and even after Giffard and Dupuy de Lôme had shown how the screw might be applied, it was not till within the last year or two that the weight of the motor and its stores had been so reduced as to give any hopeful prospect of useful results. That there is now such a prospect, so far as mechanical reasoning can justify it, hardly admits of a doubt.

Digitized by Google

Practical Considerations.

It only now remains to inquire into some of the more important considerations bearing on the question in a practical point of view.[1] And these divide themselves into two classes:—first, as to the construction of the balloon, and secondly, as to its use.

In regard to the first head, the provision of the gas, and its preservation in an envelope that shall be at once light, impervious, and strong, are conditions of ordinary study for balloons generally. M. Giffard devoted much attention to them, and the large captive balloons he constructed were filled with hydrogen at a very moderate cost, which was retained for a long period with scarcely any loss. M. de Lôme also considered his arrangements in this respect satisfactory. All other matters of a strictly aeronautical character, may safely be left to the many eminent experts in the art.

But for this purpose an unusual form of balloon is necessary, and important questions arise as to its stability. M. de Lôme, with his great experience in analogous questions in naval architecture, saw the importance of this point, and took great pains to investigate the problem. His reasonings may be found fully detailed in the "Comptes Rendus," and it will suffice here to say that he not only determined the stability theoretically, but found his expectations fully borne out by the result of his trial. M. Giffard before him had had doubts on the subject, but adds that his experiment had fully reassured him, and had shown that the use of an elongated balloon was in all respects the most advantageous possible.

As an instance of the care bestowed by M. de Lôme on the mechanical design, one contrivance is worth mention. As a balloon rises or falls, the contained gas expands or contracts in bulk, by reason of the variation in the atmospheric pressure. With the ordinary globular balloon the envelope is only partially filled at starting, and room is left in the lower part for the expansion. But with a navigable balloon it is desirable that the external shape should be maintained smooth and unaltered at all elevations. This M. de Lôme accomplished by taking advantage of a suggestion made by General Meusnier at the end of the last century, namely, by putting inside the balloon an air-pocket, or reservoir, the expansion or contraction of which would compensate for any

[1] The Author has found it necessary, for the sake of completeness, to incorporate in this Paper some passages previously published elsewhere.

Digitized by Google

difference in the bulk of the gas caused either by variation in height or by loss in escape or leakage. This internal vessel was controllable from the car, and it might be given a more extended application in regulating the vertical movements of the balloon generally. M. de Lôme states that the behaviour of his balloon, not only as to stability, but as to ease of management, was all that could be desired.

In regard to the propelling apparatus, the design of a suitable steam motor would be only a simple task to mechanical engineers accustomed to work of the kind. The construction of the propeller itself would involve more difficulty, owing to the absence of experience on any large scale of power and speed; for in large balloons it must be of considerable size. M. de Lôme made one of 30 feet, which appears to have answered very well for his small speeds; but with the higher velocities the thrust would be of course increased. The 30-feet screw, when propelling at 20 miles an hour, would have to convey a thrust of about 360 lbs., and this would require a corresponding increase of strength. For the largest balloon in the Table the screw must be 60 feet diameter (about the usual size of a windmill), and it would convey a thrust of about 3,000 lbs. The design and construction of such screws, so as to make them combine the necessary strength with the necessary lightness, would no doubt call for considerable mechanical skill.

There is also another point requiring attention, in regard to the position of the screw. To maintain perfect stability during the propulsion through the air, the propelling force ought to act in a horizontal line with the centre of all the resistances, which would be a little below the line of the axis. When it is placed lower, there results a tendency to throw the balloon a little out of level. M. de Lôme calculated this, and found the deflection was, in his case, less than a degree, which was inappreciable. At higher speeds it would be increased, and probably, with a 100-feet balloon, propelled at 30 miles an hour, it might amount to several degrees, and its effect would require correction in some way.

An arrangement must also be made to meet the disturbing effect of the loss of weight by the consumption of fuel and water, without wasting the gas; probably M. de Lôme's internal pocket might be made useful for this purpose also.

These are, however, after all, only matters of practical mechanics, and one cannot doubt the ability of engineers of the present age to deal with them satisfactorily if the requirement should arise. On the ground, therefore, of practical construction, there appears no reason to doubt the feasibility of carrying out the

Digitized by Google

principles arrived at by theoretical considerations. It is possible that by practical necessities the estimated weights or resistances might be somewhat increased; but there is considerable margin for this, and it must be borne in mind that all the data have been taken on things as they are. When the whole arrangement came to be carefully studied and tried, it is certain that improvements would take place, and what might be lost in some particulars would probably be recouped in others.

But, assuming that dirigible balloons can be constructed, it is desirable further to inquire what practical considerations might affect their use.

It is hardly necessary to say that the introduction of a locomotive machine which would transport a large number of people through the air, in any direction required, at the rate of 20 or 30 miles an hour, would be a remarkable novelty, and would offer many advantages. Comparing it with ships and boats, it would be far swifter, much less expensive in first outlay and cost of working, would require no harbours, would produce no sea-sickness, and would escape the greatest dangers inherent in water navigation. As a means of land transport, it would be quicker than common road travelling, and would compare fairly with the ordinary speed on railways, while it would dispense with the costly provisions requisite for both these modes of getting over the ground, and would be free from the multitude of liabilities to accident attending them.

But it may naturally be objected that such a mode of locomotion would have peculiar dangers of its own. No doubt balloons have hitherto been very subject to accidents, and the bare idea of anything going wrong at a height of thousands of feet above the earth is very appalling. But much of this impression will vanish before common-sense reasoning. It must always be borne in mind that for the purpose of locomotion there would be no reason for ascending high into the air; it would only be necessary to keep at a sufficient altitude to clear terrestrial impediments, and this would not only do away with much of the terror of the idea, but would greatly increase the probability of a safe escape from accidents of whatever kind.

It is worth while to consider in what direction danger might, in extreme cases, lie. The loss of gas, by rupture of the envelope or otherwise, is a remote possibility; but the experience of many actual cases has proved that the resistance of the air to the large surface exposed has sufficed to prevent any rapid fall. Special

Digitized by Google

measures might be easily provided, and at low elevations over land no serious catastrophe need be feared on this ground. In crossing over water precautions would still be possible, and the case would not be so hopeless as in many marine casualties. The danger of fire, if properly guarded against, need not be greater than in a ship at sea. Indeed, M. Giffard, who has tried the experiment, expressly states that the idea of such danger is quite an illusion.

The accidents that arise to ordinary balloons almost always occur in the descent, which, if the wind is high, requires great care and skilful management. In this case the propelling power would be most especially useful; the aeronaut could choose his place of landing with precision, and by turning his head to the wind he could avoid the dragging which is so dangerous, and which has so often brought a fatal termination to balloon voyages.

On the whole there can be no good reason to believe that the danger would be more formidable with this than with other kinds of locomotion. One cannot ignore the frightful casualties that so frequently now occur in land, river, and sea traffic; and when it is considered how many of their causes would be absent in the free paths of the air, one may even venture to assert that balloons would be the safest, as well as the pleasantest, mode of travelling.

As a set-off against this, however, there is one great disadvantage attending aerial locomotion, namely the *uncertainty* it must always be liable to, in consequence of the effect of the wind. The course of any floating vessel is naturally affected by the general motion of the medium in which she floats. With water the currents may amount to a few miles an hour; with air they will be much more, so much as seriously to interfere with the locomotive capabilities of the balloon.

According to data gathered from the meteorological reports of Greenwich Observatory for the year 1877, it appears that—

		Miles per Hour.
During 17 days in the year the mean velocity of the wind was between		0 and 5
„ 103	„ „ „ „	5 „ 10
„ 127	„ „ „ „	10 „ 15
„ 75	„ „ „ „	15 „ 20
„ 29	„ „ „ „	20 „ 25
„ 10	„ „ „ „	25 „ 30
361		
„ 3	„ „ „ „	30 „ 35
„ 1	„ „ „ „	35 „ 40
365		

Digitized by Google

The mean over the whole year was 13 miles an hour. At higher levels these velocities are exceeded; but, as has been before stated, if balloons were used for the purposes of locomotion, there would be no necessity for them to travel at any great altitude.

Now the course of a navigable balloon will be, like that of a steamer in a tideway, a compound of its own independent velocity with that of the general motion of the surrounding medium. This can easily be calculated by the ordinary rules of navigation, and the following Table shows the manner in which the composition of the two motions will influence the locomotive capability of the moving body. It is formed on the assumption that an independent speed of 30 miles an hour might be given to the balloon, and that the wind blows with velocities varying from 0 to 50 miles an hour. The wind is assumed due north, but the relations will be the same for any other direction.

Aerial Navigation.

Table showing the speed, in miles per hour, that could be commanded on any proposed course, by a dirigible balloon having an independent motion through the air of 30 miles per hour. Wind supposed due north, blowing with velocities varying from 0 to 50 miles per hour.

Proposed Course.

Velocity of Wind.	N.	N.N.E. or N.N.W.	N.E. or N.W.	E.N.E. or W.N.W.	E. or W.	E.S.E. or W.S.W.	S.E. or S.W.	S.S.E. or S.S.W.	S.
Calm	30	30	30	30	30	30	30	30	30
5	25	25	26	27	29	31	34	35	35
10	20	20	22	25	28	33	37	39	40
15	15	15	17	20	25	32	39	44	45
20	10	10	13	16	22	31	41	48	50
25	5	5	7	9	17	29	43	51	55
30	..	..	..	..	..	22	43	56	60
35	..	..	..	..	..	..	42	59	65
40	..	..	..	..	..	..	38	63	70
45	..	..	..	..	..	..	..	67	75
50	..	..	..	..	..	..	..	70	80

The practical result of this would be as follows:—

(1.) In storms and gales, say exceeding 40 miles an hour, it would not be prudent for the balloon to travel at all. Ships only sail "wind and weather permitting," and balloons must submit to the same restriction.

Digitized by Google

(2.) In high winds, say from 30 to 40 miles an hour, it could only go in a course generally corresponding with that of the wind; but it would still have a considerable range of direction and a high velocity, and, what is of the greatest importance, it would have the power of steering, and would be able to command its descent at any time, and in any place, without danger.

(3.) In light and moderate winds, under 30 miles an hour, which the Greenwich observations record to prevail all the year with the exception of a few days, it could travel in any direction, the speed varying from 5 to nearly 60 miles an hour.

It must also be added that with contrary winds the voyages must be necessarily short distances at a time, from the impossibility of carrying large stores of fuel and water to keep up the full power for any long period. But with favourable winds, such as the trades, almost any distance might be run, as the use of the engine would be limited to what was necessary for steering purposes.

These conditions would no doubt render aerial navigation unsuitable for traffic that requires regular and punctual transit, and would therefore much limit its commercial value. It could never, for such purposes, compete with railways, or lines of river or sea navigation. But still a great variety of cases exist where its peculiar advantages would tell in practical use; and probably, if such a means of locomotion were once introduced, increased employment for it would soon arise.

Summary.

The foregoing investigation appears to warrant the following conclusions.

1. The problem of aerial navigation by balloons is one as perfectly amenable to mechanical investigation as that of aquatic navigation by floating vessels; and its successful solution involves nothing unreasonable, or inconsistent with the teachings of mechanical science.

2. It has been fully established by experiment that it is possible to design and construct a balloon which shall possess the conditions necessary for aerial navigation, *i.e.* which shall have a form of small resistance, shall be stable and easy to manage, and, if driven through the air, shall be capable of steering by a proper obedience to the rudder.

3. If, by a power carried with the balloon, surfaces of sufficient area can be made to act against the surrounding air, the reaction will propel the balloon through the air in an opposite direction.

4. The modern invention of the screw-propeller furnishes a

Digitized by Google

means of applying power, in this way, to effect the propulsion; and the suitability and efficacy of such means have been shown by actual trial.

5. Sufficient data exist to enable an approximate estimate to be made of the power necessary to propel such a balloon with any given velocity through the air.

6. The recent great reduction in the weight of steam motors has rendered it possible to carry with the balloon an amount of power sufficient to produce moderately high speeds, say 20 or 30 miles an hour through the air; and by taking advantage of other recent improvements it would also be possible to carry a moderate supply of fuel and water for the working.

7. The practical difficulties in the way are only such as naturally arise in the extension of former successful trials; and such as may reasonably be expected to give way before skill and experience.

8. The practical utility of aerial locomotion must always be considerably restricted by the effect of the wind, which it is impossible for any flying body to evade. But still, such a system would have peculiar advantages of its own; and on the whole, dirigible balloons may form a feasible and useful addition to the present means of transport, and are therefore worthy the attention of the engineer.

Dec. 1881.

Digitized by Google

OBITUARY NOTICES.

MR. WILLIAM BRUNTON, one of a family which has given six members to the Institution, was the third son of Mr. William Brunton, M. Inst. C.E., and was born in Birmingham on the 3rd of April, 1817. Very early in life he showed a strong bias towards mechanics, and was articled to, and worked through the shops of, Messrs. J. and S. Seaward, of Limehouse. In 1835, at the age of seventeen, he went to the United States, where, after various vicissitudes, he became Locomotive Superintendent of the New Orleans and Pontchartrain Railway. From 1839 Mr. Brunton led a roving life, being successively engaged as engineer on an extensive sugar plantation near New Orleans, on the Manchester and Leeds Railway in England, and on the construction of the Red River Canal in the United States. In 1847 he returned home for an unusually long term, and became Resident Engineer on the West Cornwall Railway, under the late Mr. Brunel, Vice-President Inst. C.E. Being much amongst the mines in that district, he was led to study the modes of working. He invented the apparatus for washing and separating the ores from their matrix, still favourably known as "Brunton's endless cloth." Stimulated by the success attending the production of the safety fuse, and recognising the want of regularity in its manufacture, he invented a fuse-making machine of most ingenious construction. This machine he did not patent, but kept it secret, and so effectually, that the process has never been divulged. This invention has been of great service to the mining world, for, while producing an improved article, its introduction at once reduced the selling price of fuse by 75 per cent. The works producing this article, both in Cornwall and in North Wales, are still in active operation.

In September 1856 he was recommended by Mr. Brunel and Mr. Robert Stephenson (then President Inst. C.E.) for the appointment of Chief Engineer in India of the Punjab Railway, between Mooltan and Lahore, the works of which he carried on all through the Indian mutiny. He was then employed in the Public Works Department of the Government of India, until an attack of rheumatism forced him to leave the country. He elected to try his fortunes in New Zealand, where he became the leaseholder of a sheep-run of 30,000 acres. In 1871 he resumed the

Digitized by Google

practice of the profession, and became District Engineer, under Government, of the Railways in Southland, New Zealand. His professional abilities were recognised by successive Ministers of Public Works, and in his private capacity as a settler he was much esteemed, not only for his many good qualities, but for his enterprise and assistance in various objects calculated to advance the interests of the colony. In 1876 he was appointed Consulting Engineer to the Bluff Harbour Board, which post he held until the end of 1880, when ill-health compelled him to resign. On the 13th of June, 1881, he died unexpectedly at Wellington, on his way to the Hot Sulphur Springs, near Auckland, leaving a widow and seven children to lament their loss.

Mr. Brunton was elected a Member of the Institution on the 7th of March, 1854.

Mr. FRANK FITZJAMES commenced his professional career in 1856 as an assistant to Mr. J. W. James, M. Inst. C.E., on the Buffalo and Lake Huron Railway of Canada, and served for three and a half years. In 1859 he went to India, where he was first employed on the Jubbulpore line of the East Indian Railway Company, also under Mr. James, and Mr. Alexander Grant. He was then temporarily engaged on the Darjeeling Hill Road. He entered the local public works establishment in the Central Provinces in May 1862, and was occupied on the construction of the Sealdah Market, Calcutta, the Mudapoora Road, and the projects of water supply to Darjeeling. In January 1866, he was brought on to the strength of the imperial establishment of the Government of India with the rank of assistant engineer, first grade, his duties being the charge of the Korai Ghât on the Jubbulpore and Nâgpore Road, and the Saugor Road division; in the latter capacity he was instrumental in bringing to light the bad construction of the Saugor barracks, which caused a great sensation at the time. He was promoted to executive engineer, fourth grade, on the 1st September, 1867, and held charge of several divisions, during the next five years, in the Central Provinces. On the 1st of March, 1869, he became executive engineer, third grade. In 1872 he was transferred to the establishment of the inspector-general of military works, and posted to the Dinapore division, and attained another step. In December 1873 he was transferred to the N. W. P. Provincial establishment, and posted to the charge of the Muttra-Hattrass Light Railway. In

Digitized by Google

June 1874 he was appointed to the Benares Provincial division, and on the 1st of September was raised to the rank of executive engineer, first grade. On return from furlough in October 1877 he was placed in charge of the Benares district. He was temporarily employed as superintending engineer on several occasions, and was officiating as superintending engineer of the First Circle, Buildings and Roads Branch, N. W. P. and Oudh when he died, at Mussoorie, on the 9th of August, 1881, aged forty. It must frequently happen in a service like that of the Public Works Department of India that a good engineer may remain for many years without an opportunity of earning special professional distinction. This was the case with Mr. Fitzjames, who, however, was an excellent man of business, and a thoroughly good departmental officer.

Mr. Fitzjames was elected an Associate on the 1st of April, 1873, and transferred to Member on the 16th of March, 1875.

Mr. JOHN HEAD, who died on the 19th of May, 1881, was born at Ipswich on the 8th of February, 1832. He was the eldest son of Mr. Jeremiah Head, J.P., for many years one of the most respected and influential residents in the town, and an old and valued friend of the Ransome family. It seemed therefore but natural that, after completing his education at the Ipswich Grammar School, the Society of Friends' School at Grove House, Tottenham, and elsewhere, and having decided to adopt the engineering profession as his future career, young Head should become a pupil at the Orwell Works, then carried on by Messrs. Ransomes and May, and engaged on a large scale in general mechanical engineering. Accordingly in 1848 he was articled to the above firm. During the next five years he passed through the various shops and drawing-office, diligently occupied in obtaining a practical knowledge of mechanical construction, and carrying out creditably whatever was entrusted to him. At the close of his apprenticeship, desiring to extend his knowledge, Mr. Head obtained work as a fitter at the shipyard of Mr. John Scott Russell, M. Inst. C.E.; and in a short time was, on his merits, placed on the highest scale of wages current in the department.

A few months later a circumstance occurred which governed the whole future career of Mr. Head. Messrs. Ransomes and May had, prior to the outbreak of the war with Russia in 1853, undertaken

Digitized by Google

a contract for pumping engines and pumps to supply the city of Warsaw with water from the Vistula, and had arranged with an experienced mechanic to go there and erect the machinery. He, however, being unwilling to leave his wife and family under such circumstances, declined to go, and the firm were left in a difficult position. Altogether unexpectedly Mr. John Head asked to be entrusted with the work; and, after some consideration, the firm placed the responsibility in his hands, feeling that, although he had not long completed his apprenticeship, his past career justified them in so doing. The sequel proved the wisdom of their decision. There were some unexpected difficulties in the execution of the work itself; to these were added others due to the strained political relations then existing between England and Russia; but all were successfully overcome, and the works were started at the appointed time in presence of a vast concourse of the inhabitants of the country. Mr. Head subsequently received from the Emperor of Russia a diamond ring as a complimentary acknowledgment of his services. After the conclusion of this engagement Mr. Head entered as works manager the service of Messrs. Evans, Lilpop and Rau, who had a large engineering establishment at Warsaw, devoted to government work, sugar-distilling machinery, and to some extent agricultural machinery. So much had Mr. Head acquired the confidence of all around him that, when on the outbreak of war all Englishmen were ordered to leave Russia, an exception was made in his favour; and he was allowed to remain in charge of the property and the interests of Messrs. Evans, who were obliged to retire beyond the frontier.

At the conclusion of the war in 1856, Messrs. Ransomes, who had previously exported some agricultural machinery to Russia, determined energetically to develop their continental business. Accordingly Mr. R. C. Ransome, son of the then senior partner, undertook a journey through the corn-producing countries of Europe. Among other places he visited Warsaw, and sought out his old friend and fellow-apprentice, Mr. Head. A conversation which then took place led to the return of the latter to Ipswich in the following year, and subsequently to his admission as a partner in the Ipswich firm. From that time until his death Mr. Head's devotion to the interests of the firm and to the profession was incessant and untiring. He travelled repeatedly over nearly every country in Europe, carefully watching field operations and diligently searching out new applications of machinery to agriculture. He took a leading part at the great International Exhibitions, having regard not only to the interests of his own firm but also to those of his

Digitized by Google

country and of his fellow exhibitors, whom he was always ready to assist in every possible way. Mr. Head manifested great interest in the attempt to develop the use of steam locomotive engines upon common roads, by means of Mr. Thomson's system of india-rubber tires for the driving road-wheels, and in the use of straw and other vegetable substances as fuel for portable steam engines in lieu of coal or wood; and on both of these subjects he contributed papers to the Minutes of Proceedings of the Institution,[1] and received for them a Telford Medal. Whilst an Associate of the Institution he served on the Council, and subsequently became a full Member.

In the course of the year 1878 Mr. Head's naturally strong constitution began to give way under the long-continued severe strain to which his energetic temperament had subjected it. He made one or two expeditions to the South of Europe without deriving much benefit, and finally set out for the Cape of Good Hope in November 1880, determined to try the effect of wintering there. The result was, however, most disastrous. On his return to England in the following spring his case was found to be hopeless, and he died at Ipswich three weeks after. The funeral took place on the 24th of May, and was attended by a large number of friends and relatives, and by the workmen from the Orwell Works.

Of a singularly active and cheerful temperament, Mr. Head possessed a most generous disposition; prompt to recognise merit, he was slow to censure the errors or actions of any one. He was an agreeable and accomplished companion, well acquainted with life, and a true and loyal friend. He left a memory which will not soon fade from the minds of those who were only slightly acquainted with him, and which will never grow dim to those who through long years of intimate association in work and friendship knew and loved him thoroughly.

MR. JOHN FURNESS TONE, the second son of Mr. Nathaniel Tone, of Capheaton, Northumberland, was born on the 17th of May, 1822. His mother was a daughter of the late Rev. John Furness, of Ponteland. His rudimentary education was received under the Rev. J. Blyth, at Glanton, Northumberland, and his

[1] *Vide* vol. xxxvi., p. 86; and vol. xlviii., p. 75.

Digitized by Google

education was completed under the Rev. J. C. Bruce, LL.D., of Newcastle-on-Tyne.

In the year 1838, he was articled to his uncle, the late Mr. Robert Nicholson, whom he assisted in various parliamentary and constructive works, and acted as Resident Engineer on the Newcastle and North Shields Railway, and the earliest portion of the Blyth and Tyne Railway, also on the works of the Whittle Dene Water Company, for the supply of Newcastle and district. After the death of Mr. Nicholson, he was appointed engineer of the Newcastle and Gateshead Waterworks, and other undertakings of which Mr. Nicholson had been engineer. The Blyth and Tyne Railway, originally intended only for the conveyance of coal, was extended by him to Newcastle, Morpeth, Blyth, Newbiggin, and Tynemouth, and converted into a passenger line. In connection with this enterprise, he also obtained parliamentary power for a line from Gosforth to Stamfordham and Scots Gap, to join the Wansbeck Valley Railway at that time in course of construction. A company having been formed for the purpose of making a railway along the valley of the North Tyne river, he was appointed engineer, prepared the necessary plans for Parliament, and carried out the railway from Hexham to Riccarton Junction.

In the years 1857–8, Mr. Tone was actively engaged on behalf of the North British Railway Company in their contest with the Caledonian, for the possession of the line of country lying between Hawick and Carlisle, which resulted in the former obtaining an Act for a railway from Hawick to Carlisle, with a branch to Langholm, under the title of the Border Union North British Railway, which now forms a portion of the Waverley route. He then constructed that portion of the railway extending from Hawick to the English boundary at Kershope Foot; the works upon which are of a heavy character, and embrace viaducts over the rivers Teviot and Slitrig, the Shankend valley, and the Hermitage and Liddel rivers. In 1858, a line of railway having been projected from Scots Gap through Rothbury and Wooler, to join the North Eastern Company's Kelso branch at Cornhill, Mr. Tone was appointed engineer. An Act was obtained for the whole line, but only the portion from Scots Gap to Rothbury was constructed. He was also engineer for the Wansbeck Valley Railway, extending from Morpeth, past Scots Gap (where it was joined by the Northumberland Central), on to Reedsmouth, where it effected a junction with the North Tyne Railway.

In the year 1860, Mr. Tone was commissioned by the Duke of Northumberland and the Duke of Bedford, to examine the district

Digitized by Google

between Tavistock and Launceston, and to report as to the best course for a proposed railway. In 1862 he was engaged by Sir Lawrence Palk, Bart. (now Lord Haldon), Sir Baldwin Fulford, and other gentlemen in Devonshire, to lay out a series of lines subsequently known as the Devon Central railways. This scheme comprised six separate projects, namely, that from Exeter to Dunsford, from Dunsford to Chagford, from Chagford to Oakhampton, from Oakhampton to Lidford, and, descending south, from Dunsford to Newton Abbot, and to Torquay. Out of these several projects, which were presented to Parliament in 1861 and rejected, there sprang the Teign Valley Railway, which was authorised in 1863, and with which Mr. Tone was for many years associated as engineer. This line is nearly identical with that portion of the Devon Central scheme which was to run from Dunsford to Newton Abbot, as it commences in the valley a little south of Dunsford, and terminates at Chudleigh Road station by a junction with the Great Western branch, which completes the route to Newton Abbot. Whilst associated with this company, Mr. Tone was engineer for the extensions to Exeter, and to Totnes, and Buckfastleigh, which did not, however, receive the sanction of Parliament. Subsequently Mr. Tone was engineer for the line from Wells to Bristol, traversing the Somerset coal-field, and cutting through the Mendip Hills. This line starting from Radstock, however, instead of Wells, was authorised in the year 1863, under the name of the Bristol and North Somerset Railway, and for this company he continued to act for some years. In noticing the southern lines with which Mr. Tone was connected, mention should not be omitted of the Severn Valley Railway, laid out in 1853 by him under the direction of Mr. Nicholson, and which was shortly afterwards constructed, and became absorbed in the Great Western Railway Company's system.

At the time when the River Tyne Commissioners were commencing the improvements to the river, which have resulted in converting a shallow and tortuous passage into a deep-water dock and harbour of refuge, Mr. Tone was consulted by them and gave valuable assistance.

In 1862, an Act was obtained for a gravitating water supply to the Consett and Shotley Bridge districts in the County of Durham. For this Mr. Tone was engineer, and the works were constructed under his direction. He also erected a pumping engine, and constructed reservoirs for the North Shields and Tynemouth Water Company. He projected a scheme for supplying the southern coast district of Northumberland with water from the springs

Digitized by Google

issuing from the Simonside hills, and reported to the Workington Local Government Board upon the supply of water to Workington, Cockermouth, and Maryport. He also reported upon the Birmingham Sewage system, and gave evidence in Parliament upon a variety of schemes for railways and other works. In 1863 he prepared the plans for a railway from Edinburgh to Dunfermline, which obtained the royal assent. And in 1878, he reported, with an estimate of cost, upon a project for forming a dock at Blyth, with coal-shipping facilities and railway communication with the various collieries in the neighbourhood.

In 1862, the North British Railway Company having determined to take into consideration the practicability of establishing a more direct and convenient route between Edinburgh and the North of Scotland, the then Chairman of the Company (the late Mr. Richard Hodgson Huntley) consulted Mr. George Robert Stephenson, Past-President Inst. C.E., and Mr. Tone, who eventually submitted a joint report favourable to the project. In this report Mr. Tone more particularly devoted his attention to the sections and soundings, and to drawing out a statement of the interests of the various railway companies which would derive benefit from it, leaving to Mr. Stephenson the duties of preparing the bridge design and the estimates of cost.[1] This was the first design for railway communication across the Firth of Forth by means of a bridge. One of the latest works upon which Mr. Tone was engaged was a scheme for the reclamation of a considerable tract of tidal land in Morecambe Bay, the estimated cost of which was £2,500,000. He was for several years a member of the Newcastle Town Council, as one of the representatives for Jesmond Ward, and in the debates of that body, he took an active part, especially in sanitary questions. When the British Association held its meeting in Newcastle in 1863, he contributed a paper on "Railways and Locomotives on the Rivers Tyne and Tees," accompanied by a map.

Mr. Tone was elected a Member of the Institution of Civil Engineers on the 3rd of March, 1857. For some years prior to his death, which took place on the 6th of September, 1881, his health had been giving way, and during the last two years of his life, he was incapacitated from attending to any professional duties.

---

[1] The plans for this work were deposited, but the scheme had to be withdrawn in consequence of requirements by the Board of Trade.

Digitized by Google

MR. JAMES GREY ADAMSON, the eldest son of Mr. John Adamson, who was for many years an engineer in the Russian Navy, was born in Glasgow on the 15th of December, 1839. On the death of his father at Cronstadt, his mother and family removed to the town of Leven, in Fifeshire, and at the National School there he received a sound and well-grounded education. At the age of sixteen he was apprenticed for a period of seven years to the firm of Messrs. Henry Balfour and Co., general engineers and iron-founders, Leven, and, after passing through the drawing offices, as well as the pattern, turning and fitting shops, he received a certificate of honourable completion of apprenticeship.

Mr. Adamson proceeded to London in 1863 to seek his fortune, and in a few months was engaged to erect the machinery, and afterwards to undertake the general management, of a silver amalgamating and refining works near San Juan, in the Argentine Republic. There he remained for four years; but the scarcity of metals, and a widespread revolution breaking out in the Republic, caused the works to be abandoned, and the English-speaking population to seek shelter and protection in the adjoining Republic of Chili. Crossing the Andes in midwinter by an almost forsaken pass with the aid of two mules only, the usual passes being in possession of the revolutionists, Mr. Adamson, with his wife and child, saved their lives and the few valuables they were able to carry with them.

After a short residence in Valparaiso, Mr. Adamson turned his attention to the manufacture of nitrate of soda, on being appointed engineer to the nitrate works at La Noria, Province of Tarapaca, Peru. On the occurrence of the earthquake there in 1868, Iquique, Arica, and many towns on the west coast were destroyed, and he underwent much anxiety and fatigue in order to provide water for the people, as all the condensing machinery was washed into the sea by the earthquake wave.

A few months later the nitrate fields in the Desert of Atacama were discovered, near to what is now the flourishing town of Antofagasta, since become famous in connection with the war between Chili and Peru. Having erected distilling works near Salar del Carmen, a few miles from Antofagasta, the manufacture of nitrate was carried on with great success for a few years, till the field of nitrate ground, or "Caliche," was exhausted. Fresh fields were, however, discovered about 60 miles inland. Mr. Adamson, with his varied and general knowledge of mechanics and chemistry, designed a complete plant on principles entirely

Digitized by Google

new, to be erected at the Port of Antofagasta, connecting the "Caliche" beds with the works by a narrow-gauge railway. This design had the entire approval of what is now the great nitrate and railway company of Antofagasta (Compania de Salitres y Ferro Carril de Antofagasta).

In 1875 Mr. Adamson was sent to this country to procure the necessary machinery, in conjunction with Mr. J. F. Spencer, M. Inst. C.E., engineer to the company; and, not forgetting the works where his mechanical knowledge had been so well founded, the larger part of the order was placed in the hands of Messrs. Balfour and Co., as well as the contract for the erection of the complete plant at Antofagasta. It was while on a visit to this country in connection with the above work that Mr. Adamson joined the Institution of Civil Engineers as an Associate Member. He returned to Antofagasta, in 1876, to prepare the foundations for the ironwork and machinery, and passed through anxious months during the erection of the works and subsequent practical trial of his designs in nitrate production. These works are now a landmark to every traveller on the west coast of South America, and when the history of the war between Chili and Peru is written, the Compania de Salistres y Ferro Carril de Antofagasta will probably be prominent. Although situated in Bolivia, the nitrate beds were leased by Chilian and English capitalists, under favourable conditions, from the Bolivian Government, ratified by the Chilian Government. The company's profits and output were so great, that jealousy arose on the part of the Bolivian and Peruvian producers of nitrate, whose markets were disturbed. A demand was accordingly made by the Bolivian Government for an extra tax on the output beyond the conditions of the original contract, which compelled the company to appeal to the Chilian Government for protection, the result being a declaration of war between the neighbouring Republics.

Mr. Adamson, during the visits of the Peruvian ram "Huascar" in the bay, held to his post and visited several of the battle-fields, his house becoming almost the headquarters of the officers of the Chilian army garrisoning the town. The excitement of the war, an accidental fall of 18 feet whilst at his duty on the works, the poisoning by noxious vapours whilst examining the boiler flues, and the worry incidental to the management of works of this magnitude, tended to impair his strength, and in addition an acute attack of liver complaint, necessitated his removal to a milder climate. Arriving at Valparaiso he sought the best medical assistance obtainable at the English hospital there, but his case

Digitized by Google

was pronounced hopeless from the first, and he expired on the 14th of May, 1881, at the age of forty-one years.

Of the personal worth, unbounded kindness and hospitality, of Mr. Adamson, Englishmen visiting Antofagasta can well testify, and the premature death of so valuable and useful a life will long be regretted on the West Coast. A monument has been erected over his grave by his friends, including the workmen who were under his care. Mr. Adamson leaves a widow and a young family to mourn his loss.

Added to nitrate production, Mr. Adamson erected a complete plant for the extraction of iodine,—for the distilling of water for drinking purposes from sea water, which only was available,—as also works for the manufacture of the gunpowder required for the blasting purposes of the company.

MR. WILLIAM EXALL was born at Godalming, Surrey, in May, 1808. Two years later his father emigrated with all his family to America, settling in Richmond, Virginia. William was apprenticed to a bookseller and bookbinder, but young Exall's connection with bookbinding ceased with his apprenticeship. Possessing considerable mechanical ability, and desiring a sphere in which he would have an opportunity of cultivating this faculty, he joined his two brothers in establishing a business as agricultural machinists at Richmond, in which the brothers were successful. About the year 1830 their uncle, Mr. Barrett, who then carried on what was known as the Katesgrove Foundry, Reading, invited Mr. William Exall to come over and assist him in the business, and he complied with the proposal. On arriving his energies were at once devoted to the improvement and development of agricultural machinery, and eventually he was admitted a partner of the firm.

During the construction of the Great Western Railway, Mr. Exall, through his engineering knowledge, was brought into contact with the late Mr. I. K. Brunel, Vice-President Inst. C.E., the engineer of the Company, and his numerous staff. It need hardly be said that this connection proved very advantageous, for it brought a large accession of business to the Katesgrove Foundry, which began to assume considerable importance as a place for the manufacture of machinery of various kinds. The connection between the firm and the railway company continued until the main line was finished, and during that period Mr. Exall worked with the

Digitized by Google

vigour and tenacity of one who combined spirited enterprise with a love of work, though his intense industry seriously impaired his constitution.

By degrees as the railway works slackened, Mr. Exall directed his attention more to general and agricultural engineering, in which he was very successful. He was the inventor of the patent safety cylindrical horse gear, which has become a standard mechanism both in Europe and in America. He was also the inventor of the endless-band sawing machine, but the idea was patented by another, for Mr. Exall's purpose was rather to originate new ideas, without any definite object of pecuniary gain, although many patents were registered in his name. He was the first to apply the double-acting air-pump, or box-shaped condenser to horizontal engines, the air-pump being a prolongation of the piston-rod through the back cover of the cylinder in the same line. He was also the pioneer of steam cultivation, having constructed the first set of machinery on the roundabout system, in 1849, and superintended its working for Mr. H. J. Hannam, of Buscot Park, in Oxfordshire. He was likewise among the first in the application of the portable form of steam engine as applied to agricultural operations.

In the early years of Mr. Exall's connection with Reading the celebrated "Swing" riots had so alarmed agriculturists, that the farmers of the district, whose horse-power threshing machines had not been broken up by the rioters, brought them into the foundry yard for safe custody, where they remained for many years, and were mostly broken up, being too clumsy for use when the panic had ceased. As time passed on Mr. Exall perceived that with increased quietness there was an opportunity for again introducing machinery, and he constructed the first hand-power threshing machine, an innovation of so simple a character that the labourer did not resent its use. In 1844 one of these machines was exhibited at the Southampton Meeting of the Royal Agricultural Society. In the Report on the Exhibition of Implements, the following passage occurs, "Of the hand-threshing machines the judges observe, 'That which we considered to possess the greatest merit for originality of design, as also in its performance, was exhibited by Messrs. Barrett, Exall and Andrewes, of Reading. We highly commend this machine as likely to be useful in populous districts. Several others seem to have been copied from it.'"[1] Thousands of these machines were made by the firm,

[1] *Vide* Journal of the Royal Agricultural Society, vol. v. (1845), p. 384.

Digitized by Google

and it is not difficult to trace the rapid onward progress of them as the hand-power gave way to the use of a horse, then to two, three, and four horses, until the era of steam-power was ushered in.

Mr. Exall was essentially an inventor, but was indisposed to follow up his inventions to a practical personal advantage. Science was followed by him for its own sake and for its practical value to Society, and nothing afforded him a purer delight than to assist a brother mechanician in working out and perfecting an idea. He was extremely fond of geographical studies, both general and physical. His fertility in resource in case of emergency was another peculiar feature in his character; a difficulty to be surmounted was a pleasure to him.

He was prominently associated with the public life of Reading for over thirty-five years. He entered the Town Council in November 1845, was chosen Alderman on the 31st of March, 1854, and was elected Mayor in November of the same year. Ten years later he was made a Justice of the Peace for the borough. This last-named office and the position of Alderman he retained to the time of his death. He was very regular in his attendance to the business of the Council, and his active interest in its affairs continued to the last, his final appearance among his colleagues being on the 2nd of June, 1881, on which day he attended meetings of the Council and the Watch Committee. In the establishment of the celebrated biscuit factory of Messrs. Huntley and Palmer, Mr. George Palmer, M.P., availed himself largely of Mr. Exall's engineering knowledge.

Mr. Exall was a man of considerable force of character, and, though not gifted with the power of eloquence, his sound sense never lost its effect on those whom he addressed, and his geniality and urbanity of demeanour towards those with whom he came in contact won him the respect of all classes. He was twice married, first, in 1838, to a daughter of Mr. Andrewes, of Hounslow, and, secondly, in 1863, to Miss Ibbetson, of Halifax, Yorkshire, who survives him.

Mr. Exall was elected an Associate of the Institution on the 3rd of December, 1850, and occasionally contributed to the discussions.

Mr. ALEXANDER MANSON RYMER-JONES, the second son of the late Professor Thomas Rymer-Jones, of King's College, London, was born on the 15th of July, 1845. Articled to Mr. F. Campin, he studied with that gentleman as a civil and mechanical

Digitized by Google

engineer until 1866, when he proceeded to Madras and joined the contractors on the Madras Railway as assistant agent, carrying out under them several important works. Returning to England in 1871, he was employed by the late Mr. James Samuel, M. Inst. C.E., on the Mexican railways until 1872, and on the Boliva Railway by Messrs. Barnett and Gale, from 1873 to 1874, resigning on the transfer of the contract to other hands. Subsequently he served at the Cape of Good Hope as engineer for roads and bridges, from 1875 to 1877. In June 1880, he was engaged on the Conde d'Eu Railway, in Brazil, for Messrs. Wilson, Sons and Co., but owing to an attack of malarial fever, he had to return to England to recruit his health. He then proceeded to Spanish Estremadura for Messrs. Matheson and Co., to carry out large railway works, but a return of malarial fever accompanied by dysentery caused his death on the 5th of October, 1881, at the age of thirty-six. Amongst his various inventions was an automatic levelling machine, called the "Temnograph,"[1] the perfection of which his early death prevented him from witnessing, but which has since been brought to completion. He was elected an Associate Member of the Institution on the 3rd of December, 1872.

MR. JOHN SLATE, the third son of the late Archibald Slate, Assoc. Inst. C.E., was born at Dudley, on the 14th of May, 1849. When a boy he was placed as a private pupil with the Rev. J. H. Bennett, at that time Head Master of the Solihull Grammar School, near Birmingham. There he remained, getting an ordinary grammar school education, till he was between sixteen and seventeen years of age, when it was thought desirable that he should turn his attention to engineering. Some works were in course of execution at Lichfield at that time for increasing the supply to the South Staffordshire Waterworks, under the direction of the late Mr. J. R. McClean, Past-President Inst. C.E., as the Company's engineer. The operations were carried out by the Company, without a contractor, under the charge of Mr. David Thomson, M. Inst. C.E., as resident engineer, assisted by Mr. R. A. Robertson, M. Inst. C.E., and young Slate was placed at Lichfield, to make himself useful and learn what he could on the works. These works were finished in 1867, and Mr. Slate's conduct and progress having been satisfactory, Mr. Thomson

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxi., p. 268.

Digitized by Google

procured him admission, without premium, into the establishment of Messrs. R. Moreland and Son, Manufacturing Engineers, in London. Here his preliminary experience and aptitude enabled the firm at once to place him in the drawing office, where he continued, except for a few months in 1868-9, when he was sent to Devonport Dockyard to superintend the erection of some machinery.

In the meantime his friend Mr. Robertson had become connected as manager with the largest sugar refinery in London, and in 1871 he recommended Mr. Slate to a somewhat similar appointment in the works of Messrs. A. N. Gadesden and Co. Here he remained till 1876, when changes in the sugar trade caused the works to be closed. He had, however, given so much satisfaction to the firm, that Mr. Gadesden, kindly recommended him to the Colonial Company as managing engineer at their Usine Madelaine, Trinidad. In this position, although new to much of the work, he achieved great success. He thus, at an early age, gained considerable reputation among the West Indian sugar estates, and seemed to have fairly laid the foundation of his own fortunes, when, in the early spring of 1881, his health gave way and he had hastily to retire from the West Indies on being assured that he could not survive a prolongation of his residence there for even a few weeks. On coming home he went to Margate in the hope of recruiting, and there, on the 16th of August 1881, he met with his death suddenly, from accidently taking poison in mistake for medicine.

Mr. Slate's career was too short to have produced results remarkable in themselves, but it was noteworthy in that, whereas at school he had no education specially directed to engineering, and even very slight instruction in mathematics, he at once became both useful and trustworthy in taking levels and bearings in the tunnel works on which he was engaged. Further, at Messrs. Moreland's works, although never employed in the shops or in the manual use of tools, he became quickly remarkable for his practical knowledge of details, and for his acquaintance with the workmen, and the methods of executing different kinds of iron-work. Moreover, he had no previous instruction in the processes of a sugar refinery, nor even in the elements of chemistry, yet with the occasional assistance and advice of his friend Mr. R. A. Robertson, he soon succeeded in acquiring the necessary knowledge for conducting the work.

Mr. Slate was elected an Associate Member on the 4th of May 1875, and had previously been a Student.

Digitized by Google

MR. THOMAS LANFEAR TANNER was born at Welford, near Newbury, Berks, on the 4th of November, 1844. He was educated at Aldenham Grammar School, near Watford, Herts, and at King's College, London, and was then articled to Mr. Thos. Olinthos Donaldson, M. Inst. C.E., for three years. During his pupilage, he was employed on the Dorset Central railway, and also on the Team Valley railway, now a portion of the North Eastern system.

At the expiration of his pupilage in August, 1866, he studied privately for some time in order to qualify himself for the Public Works Department of India, and was successful at the examination, but preferred to accept an appointment on the Great Indian Peninsula Railway, obtained through the influence of Mr. Gregory, Past-President Inst. C.E. He went to Bombay in June, 1869, and remained in the service of the company for three years, during a portion of which time he was employed in taking trial sections for an alteration of the Bhore Ghât Incline, after the disastrous accident of a train overrunning the reversing station.

He was then in the service of Messrs. Glover and Co., contractors, as their engineer, on the Wudwan Extension of the Bombay, Baroda, and Central India Railway, about eighteen months. In March 1873 he applied for and obtained an appointment in the Public Works Department, and was employed on the Darjeeling Railway, on famine works in the Punjab, and on the Punjab Northern State Railway. In a letter from him dated Pind Sultane, Rawal Pindi, July 18th, 1880, he says, "My work has been the construction of 40 miles of line (frontier line), towards Kohât. I am at the upper end, and it is a fearful outlandish country to be in; but I can talk the language, and have men with me who have been with me on old works. My servants, too, are most of them five to seven years men, so really I have little difficulty. I commenced work in November last surveying only. Since then, I have built—

2 × 4 Bridges, 60 feet span, 35 feet high.
1 „ 60 „ „ 25 „ „

besides numerous small bridges, and completed the banks and cuttings (two of which are hard rock), for forty miles; Government gave me four assistant engineers, young hands. We spent steadily £3000 a month, and all by contract. I am now simply putting up some 60-feet Warren girders, and building the stations. The rails are delayed owing to accident below. I have four stations on my length, one being a terminus."

Digitized by Google

Mr. Tanner was elected an Associate on the 6th of December, 1876. He died at Belput, on the Kandahar line, on the 29th of June, 1881, from heat apoplexy, after a few hours' illness, and was buried in the cemetery at Jacobabad. At the time of his death he had attained the rank of third grade executive engineer.

Mr. HAMILTON ELA TOWLE was born at Lee, New Hampshire, on the 24th of June, 1833, and was the son of Mr. Gardner Towle, a prominent man in that part of the State. In 1848 he acquired his first interest in Civil Engineering by serving as general utility boy with a party making the surveys for the Portsmouth and Concord Railroad. Under these conditions he began his preliminary studies in mathematics with the view of becoming an engineer. In 1852, after having spent nearly three years in the office of Mr. W. Q. Dow, engineer of the basin and railway works constructed for the United States Government at Portsmouth navy-yard, as a pupil and assistant, he was engaged as first assistant at the basin and railway works, Pensacola navy-yard, where he remained for a year, when he resigned in order to study higher branches of engineering. After a few months' preparatory course under a private tutor, he entered the engineering school of Harvard University (known as the "Lawrence Scientific School"), from which institution he graduated with the degree of Bachelor in Science (B.Sc.) at the end of two and a half years. He then accepted the position of assistant engineer, with entire charge of the construction for the Government of Fort Montgomery, of one hundred and thirty-one guns (with pile foundations requiring the construction of cofferdams, and pumps, &c.), at the head of Lake Champlain, New York State, where he remained for two years.

In January 1857, he went to Austria, residing there during the construction of the dock basin and railway works at Pola, a period of three and a half years. He personally made all the designs and calculations for the contractors, Messrs. J. S. and A. H. Gilbert. Of this work Mr. Towle in 1871 presented a full account to the Institution, for which he received a Telford Premium.[1]

After six months' travel and inspection of the seaports of Northern Europe, Mr. Towle, in the latter part of 1860, returned

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol.

Digitized by Google

to America, and in 1861 again visited England and France on professional business. While returning to New York by the "Great Eastern" in September 1861, he was able to render valuable advice and assistance under the following circumstances. Consequent upon a great storm, the rudder-head had broken below the tiller, and the ship lay unmanageable in the trough of the sea. A "drag" or spar towed from the stern was of no avail in assisting to steer the vessel, when Mr. Towle suggested a device that was ultimately successful in causing the ship to answer her helm. Two 15-fathom lengths of the great chain cable were dragged aft: one end of each of these chains was made to take a turn round one of a pair of bollards and the other ends were similarly secured to the rudder-post; then, by slacking out a link on one side, and hauling in on the other, sufficient play was given to the rudder to keep the vessel fairly on her course. The ship was put about and entered Cork Harbour in safety nine days after leaving Liverpool. For this service Mr. Towle's fellow-passengers presented him with a gold watch, and the Life-Saving Benevolent Association of New York awarded him a gold medal and an address.

From 1861 to the time of his death Mr. Towle was in practice on his own account as a Civil Engineer, during which time he laid out and constructed a branch mineral railroad for the "Tilley Foster Iron Mines" of New York, and arranged a plan for working the mines, and designed and superintended the construction of an entirely new plant—consisting of pumps, steam-engines, narrow-gauge tracks, ore wagons, &c.; he likewise superintended the construction of the Mineola and Glen Cove branch of the "Long Island Railroad Company, New York." He was consulting engineer to the "New York Belting and Packing Company," and was frequently engaged in examining and reporting upon various machines. Mr. Towle invented and constructed many machines appertaining to the arts, among others a loom for weaving heavy fabrics, for the manufacture of which a company was started, known as the "United States Loom Company," of which he was the manager. He was elected an Associate of the Institution on the 5th of March, 1872.

In December, 1874, Mr. Towle went to South America in the interests of the Colombian Government to examine and report upon the bed of the Magdalena river. In 1877 his health broke down, and by the advice of his physicians he made a prolonged tour in Europe. Returning to New York in October 1878, he was soon after again compelled to cross the Atlantic. From this time he gradually grew weaker, and died on the 2nd of September,

Digitized by Google

1881, at the residence of his son-in-law, at Upper Norwood, near London, in his forty-ninth year.

Mr. Towle's predominant qualities were great inventive faculty, quick, ready ability to provide for sudden emergencies, and simplicity and thoroughness in the measures adopted for meeting them.

Mr. JOHN HAMILTON WICKSTEED, born at Leeds on the 21st of January, 1851, was the fifth son of the Rev. Charles Wicksteed, B.A., and nephew of the late Mr. Thomas Wicksteed,[1] M. Inst. C.E., the well known waterworks engineer. When young Wicksteed was three and a half years old, his father removed to Hafod-y-Coed, near St. Asaph, owing to failing health, and here his education was conducted till he was fourteen, when he was sent to University College School, London. Two years later he was articled to Mr. Edward Filliter, M. Inst. C.E., of Leeds, with whom he remained as pupil and assistant for ten years, and by whom he was employed on several works of water-supply and sewerage. While thus engaged he came under the notice of Mr. Hawksley, Past-President Inst. C.E., whose good opinion he secured, which proved invaluable to him during his ensuing brief career. When only twenty-six years old, Mr. Wicksteed received the appointment of resident engineer for waterworks to the municipality of Port Elizabeth, Cape Colony. As the inconvenience sustained at this place for want of water was very great (the commodity sometimes selling at 3*d.* or 4*d.* a quart), and as much disappointment was felt by the inhabitants at the miscarriage of some previous efforts to obtain a supply, Mr. Wicksteed lost no time in preparing himself for this undertaking. Landing at Port Elizabeth on the 29th of December, 1877, he had, within four hours of the vessel anchoring in the bay, seen the mayor and town clerk, and was in the saddle for a rough ride of thirty miles under a blazing sun, to the source of supply. The Government Hydraulic Engineer, Mr. John G. Gamble, M. Inst. C.E., residing at Cape Town, gave his entire approval to the plans and specifications prepared for the undertaking by Mr. Wicksteed, upon whom of necessity rested, almost individually, the execution. His personal supervision was minute throughout the progress of the work, the difficulty and strictness of which proved often very trying to the men. But Mr. Wicksteed had an easy

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 241.

Digitized by Google

good-humoured way of securing obedience and industry among his numerous motley gangs of labourers. An exemplification of this occurred once when,—himself working in the unceasing rain to set out the pipe-track, scrambling over slippery rocks and pushing through long grass and drenching bush—one of the white men, lately arrived from the Bay, announced his intention of going back, as such work wasn't "fit to turn a dog to." He was answered that he was quite right; that men were wanted and not dogs; and that if the aggrieved one did not feel himself as good a man as the rest, he had better go home. After meditating five minutes on these words, the man set to work again and accomplished more than any of the others that day, working well ever after. All difficulties overcome, the water was at length seen spouting up in the market-place of Port Elizabeth, above the roof of the town hall, within the specified time and within the specified estimates, and owing to the system adopted of testing the work in sections as it proceeded, without a leak or a burst in 30 miles of pipe-track. Several distinctive specialties were introduced in these works, among them an unusually short faucet-and-spigot joint, and the provision of a small air-hole through the socket, so that in running in the lead, no air might be imprisoned to honeycomb the joint at the top, even if, on undulating ground, the sockets should be pointing down hill. On the successful completion of the undertaking, Mr. Wicksteed continued in charge of it, at the request of the Council, adding also to this the functions of borough engineer and architect. This involved a large amount of additional labour and anxiety, as the draining of the town was much needed, and more than one public building had to be erected. Nothing but hard and constant personal work would meet the case in a community where there is no means of obtaining the trained assistance which an engineer at home so readily commands. Never of robust health, and from a child requiring care and attention, Mr. Wicksteed's health completely broke down under the combined effects of climate and mental strain, and he died on the 23rd of August, 1881, when only thirty years of age.

The untimely death of one so full of promise, was considered almost in the light of a public loss in the colony. On the occasion of the funeral the flag at the town hall was put at half-mast, the mayor and council were present, as were also most of the leading people. In a letter to the bereaved father, communicating a vote of condolence passed by the Town Council of Port Elizabeth, the mayor alluded in the following terms to Mr. Wicksteed's character:—"By the death of your much-lamented son, this Corporation has

Digitized by Google

sustained the loss of one of its ablest, most diligent, and most useful officers; one, moreover, whose name will for all time be associated with one of the greatest and most efficient enterprises ever yet undertaken by a colonial municipality."

Mr. Wicksteed was elected an Associate Member of the Institution on the 5th of December, 1876, and he had previously been a Student.

MR. EDWARD BENTINCK WILLIAMS, the second son of the late Rev. Preston John Williams, Vicar of Godmanchester, Hunts, was born at Southampton, on the 19th of August, 1847. He was educated at the Grammar School, Huntingdon, and in August, 1863, became a pupil in the office of Mr. R. A. Marillier, M. Inst. C.E., Resident Engineer to the Hull Dock Company, to whom, after the expiration of his apprenticeship, he was appointed assistant, which position he held up to the time of his death.

He was elected an Associate of the Institution on the 3rd of December, 1872, and died at Hull, of erysipelas, on the 9th of November, 1881, after an illness of five weeks.

CAPTAIN WILLIAM HENRY JOHNSTONE, R.E.,[1] illustrated in a short but promising career the sad fate that too often overtakes the zealous English officer when on active service in a tropical climate. He was the eldest son of the Rev. W. H. Johnstone, Vicar of Bearden, Essex, formerly Chaplain and Mathematical Professor at the Royal Indian Military College, Addiscombe, and was born at Croydon, on the 27th of September, 1846. He was entirely educated by his father, up to the time of his passing into the Military College at Woolwich, in 1865. On the 10th of July, 1867, he was gazetted Lieutenant in the Corps of Royal Engineers, and joined the School of Military Engineering at Chatham. Having volunteered for active service in India with a view to employment in the Public Works Department, Lieut. Johnstone, in November 1869, joined the Bengal Sappers and Miners, at Chakrata, in the Himalayas. Here he held command of a company of native sappers for some months, and, under the Public Works Department, repaired the Chakrata and Mahona Canal,

[1] Much of this memoir is derived from one by Major H. Wilberforce Clarke, R.E., in the Royal Engineer Journal, Oct. 1, 1881.

Digitized by Google

which supplies the former station with water. In November 1870, he joined the Holkar State Railway, and was principally employed on the triangulation of the Choral Valley. Subsequently he was posted to the Nerbudda Bridge Division, his work being the preparation of plans and estimates, also the calculations for the bridge, the design of which was submitted to Government. After a year in this capacity he was transferred to the Ghât Division, under Mr. A. C. Cregeen, M. Inst. C.E., where he remained till May 1877. Here he had charge of the subdivision, including the Mhow Ghât incline, which cost 40,000*l.* per mile. He was also responsible for four tunnels, two ravine viaducts (one of them 160 feet high), and the third Choral River bridge, and his subdivisional accounts sometimes reached 50,000 rupees monthly. While on the Ghât division, Lieut. Johnstone was made successively first grade assistant and fourth grade executive engineer. On attaining the latter departmental rank he left "construction" for open line, joining the office of the manager of the Holkar and Neemuch State Railway, and remained there for a year, engaged in routine duties, with the exception of a few weeks when he was specially deputed to report on the block of traffic on the Jubbulpore line of the East Indian Railway, resulting from the demand for grain carriage to the famine districts. In May 1878, Lieut. Johnstone was appointed to the office of the consulting engineer to the Government of India for guaranteed railways, as temporary deputy consulting engineer, his duties being principally to report upon questions arising which in any way concerned the Government control. On the 3rd of November, 1879, he was promoted to the rank of Captain, and seven months later was advanced a step in departmental rank—to third grade executive engineer, being permanently appointed, about the same time, Deputy Consulting Engineer. In the beginning of 1880 he had applied for furlough on account of failing health, but owing to the war in Afghanistan, and the Nynee Tal disaster, his services could not be spared until the end of the year. Suffering from congestion of the lungs, he arrived in England in the severe weather of January 1881. He sank rapidly from consumption, accelerated by hemorrhage, and after five months' illness, borne with exemplary patience and resignation, breathed his last on the 20th of June, 1881.

This enumeration of Captain Johnstone's short career cannot of course record any striking feature. An assistant engineer in India has not much opportunity of coming prominently to the front; he can only carry out carefully the orders given to him. That

Digitized by Google

Captain Johnstone did this in its best sense, the testimony of his superior officers abundantly shows. Mr. Cheyne, the superintending engineer of the Holkar State Railway, under whom he served, writes concerning his charge of the Ghât subdivision (Vindya Range):—"The works were of unusual magnitude, and his management was excellent. When the line was nearly finished, I walked over it with General (then Colonel) C. Pollard, R.E., who, saying that he had seen nearly all the public works in India, declared that there was nothing to be found anywhere so fine. I myself do not think it would be possible to do anything better."

After much laborious and hardly requited toil—after years of disheartening yet valuable work—Captain Johnstone had attained such a position that the future was, humanly speaking, in his hands. While his talents were of a high order, his acquired knowledge was great. In everything he was thorough and honest: work entrusted to him was executed most conscientiously. During a tour in Kashmir he collated a mass of valuable notes which he intended to put together to form a complete guide to the traveller in that country. He had contemplated the publication of his Kashmir notes while in England, but this and other plans for occupying a short furlough were frustrated by his untimely death. Captain Johnstone was elected an Associate of the Institution on the 7th of December, 1875.

MR. ANGIER MARCH PERKINS was born at the end of last century at Newbury Port, a small town in the State of Massachusetts, America. He was the second son of Mr. Jacob Perkins, for many years a member of the Institution,[1] and who distinguished himself through a long and active life by his scientific attainments, and by the number and variety of his inventions. Mr. A. M. Perkins inherited much of his father's talent and fertility of invention, as evidenced by the numerous patents granted to him between the years 1831 and 1864. He came to England in 1827, and was for some time associated with his father in perfecting and bringing to maturity several of the many inventions then in hand. Of these the following may be selected as illustrating the diversity of the inventions which the elder Mr. Perkins gave to the world, and in which the subject of this memoir was closely allied. First, a mode of engraving on steel,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 516.

Digitized by Google

and of multiplying copies of the engraved plates by transferring the same to other plates under mechanical pressure. Second, a mode of generating and using steam under very high pressure. The former of these inventions led to the establishment of manufactories both in England and in America, which are still in successful operation, for the production of bank notes and such documents in which security from forgery is important, and when a very large number of impressions is required. The invention occasioned much sensation among engravers at the time, owing to the revolution it effected in the mode of engraving by the substitution of steel for the copper-plates previously used; and it may be interesting to mention that the first adhesive postage stamps were produced by this process for all the countries of the world where the system of cheap uniform postage had been adopted.

The latter invention, viz., that relating to the generation and use of high steam, was popularly exemplified by the celebrated "steam gun." It was shown how steam might be safely and practically generated up to 2,000 lbs. pressure per square inch, and could then be kept under perfect control. This subsequently led to other and most important discoveries in connection with the use of steam at higher pressure than theretofore.

Following out the high-pressure system, Mr. A. M. Perkins applied the principle to a mode of heating dwellings and buildings by hot water circulating in closed pipes of small diameter, which has been extensively adopted. A large and successful business was the result of this patent, in the conduct of which Mr. Perkins greatly occupied himself. He nevertheless continued to carry on experiments with high-pressure steam under various conditions and for various purposes. His patent in 1843 for the manufacture and melting of iron by the use of superheated steam was remarkable, inasmuch as it evidently contained in it the germs of the subsequent discoveries relating to the conversion of iron into steel, and the elimination of phosphorus and sulphur from iron.

Later on the system of circulating water in closed pipes of small diameter, heated up to 2,000 lbs. per square inch of steam pressure, was applied by Mr. Perkins to the heating of ovens for baking purposes, which has also been extensively adopted; the uniform degree of heat at which the oven is thereby maintained being of essential benefit. An indestructible engine-boiler on the same system followed, in which the boiler is removed from contact with the fire, the heat from which is conveyed to the boiler by water circulating in closed pipes; and boilers constructed on this principle have been in continuous use for thirty-five years without

Digitized by Google

deterioration. The instances in which Mr. Perkins' attention to details, combined with his inventive powers, have rendered service to the mechanical world, by some simple contrivance, are very numerous. Few of these were the subject of patents, but the right and left hand-screw joint, which was patented by him, will be admitted to have been of essential service, especially in connection with hydraulic work. As a mode of uniting the ends of two pipes, and forming a tight joint, capable of bearing as much pressure as the pipe itself, it is at once simple and excellent. It may be added that during the whole course of the working with very high-pressure steam, from its commencement to the present time (a period of fifty years), no dangerous accident has happened nor has any life been lost.

Naturally of a retiring disposition, and with much occupation on his hands, he successfully resisted the frequent appeals of his many friends that he would take a more prominent place among his professional brethren, and give them the benefit of his great experience and undoubted abilities. Those, however, who had the privilege of his intimacy and friendship can bear testimony to the enjoyment they experienced in their intercourse with him, no less from his unaffected kindliness than from the store and accuracy of the knowledge which he was so well able to communicate. He died on the 22nd of April, 1881, at the advanced age of eighty-one.

Mr. Perkins was elected an Associate of the Institution on the 5th of May, 1840.

Mr. EDWARD ANTOINE SACRÉ was born in London on the 8th of October, 1838. In early life he pursued his studies in London and Belgium with a view to becoming an engineer. In 1853 he was articled to Mr. Archibald Sturrock, at that time Locomotive Superintendent of the Great Northern Railway, and went through the various practical departments of that railway. He soon showed so much quickness and ability, that Mr. Sturrock was induced to employ him frequently in making experiments on the consumption of coal, coke, water, &c., in locomotive engines; also in regard to the general loading of trains, more particularly in the goods and mineral service. On the termination of his pupilage he was appointed assistant to Mr. Budge, the District Locomotive Superintendent of the Great Northern Railway, at King's Cross, where he gained such experience that, on the opening of the East Kent, now the London, Chatham, and Dover Railway, he was appointed

Digitized by Google

to take charge of the locomotive department of that line. After a short time he relinquished the position to go to Australia, where he was actively engaged in responsible positions in connection with railway working, amongst others being Locomotive and Traffic Superintendent of the St. Kilda and Brighton Railway. He was also for some time engineer to a large firm of contractors, and under his control a portion of the Picton and Ballarat, and of other lines was constructed. Acting upon the advice of his family, after spending seven years in Australia, Mr. Sacré returned to England and joined Mr. H. W. Hunt as partner in the engineering firm of Hunt and Sacré, with which he was connected up to the time of his death, and when he was Deputy Chairman of the Felixstowe Railway and Dock Company.

The late Mr. Sacré had a varied and extensive experience in the design and construction of rolling stock and machinery of all descriptions, and frequently visited the United States and Canada, and most European countries. He was also the patentee of an Improved Noiseless Street Tramway Engine, which, owing to the occurrence of his illness, he was unable successfully to develop. He died in London on the 26th of October, 1881, at the age of forty-three, after a long and lingering illness, regretted by a large circle of friends.

Digitized by Google

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Apparatus for Measurement of Base Lines. By F. H. Reitz.

(Zeitschrift für Vermessungswesen, June 1881, p. 233.)

Improvements are here suggested in two details of Bessel's apparatus for measuring base lines, viz., in the shape of the ends of the measuring rods, and in the method of finding their temperature at the time of measuring.

In Bessel's apparatus the ends of two successive rods have bevelled edges, standing perpendicularly to one another, the space between them being measured by a wedge. The Author substitutes for these perfect cylinders of 5 millimetres (0·197 inch) radius, made of steel or rock crystal, as he considers that the distance between rod-ends, shaped in this way, can be more accurately determined by the wedge; this rounding of the ends makes the latter last longer, and at the same time entails less wear on the wedge. Each measuring rod is from 4 to 5 metres (13 to 16½ feet) long.

For the second improvement, tubes, preferably of drawn brass, are provided, the temperature of which is ascertained by filling them with water, and then inserting a thermometer into them. When measurements are made in winter the water is kept from freezing by the addition of alcohol or glycerine. Should iron tubes be used, an alkali must be put in the water to prevent permanent rust inside the tubes.

Sketches of the proposed apparatus are given, and the Author concludes by showing how the actual horizontal distance between the ends of his improved rods is found by the wedge.

E. H. C.

Changes in Length of Wooden Levelling-Staves.

By Prof. H. G. van de Sande-Bakhuyzen.

(Zeitschrift für Instrumentenkunde, Sept. 1881, p. 277.)

The influence which weather exercises on wooden levelling rods induced the Author to make continuous comparisons on a pair of staves used in the Netherlands spirit-levelling. These staves were T-shaped, 3 metres (10 feet) in length, and made of fir;

Digitized by Google

they were fitted with box-levels, and handles for laying them down without risk; their zero point coincided with the under-plane surface of a steel shoe, surrounded by a copper strap. On the face of the staves were fixed small steel studs, about 95 centimetres (37½ inches) apart, in copper boxes let into the wood. Each pair of staves had its steel standard rod with attached thermometer, and as this rod is only 93 centimetres long, the interval between it and any two steel studs is measured by means of two small wedges, which are screwed into the vacant spaces.

To determine the length of the staff itself a square metre rod of steel, divided to millimetres, was laid upon the levelling-staff so that its graduations were perpendicular to those on the staff, when it could be easily seen how much the reflected graduations differ from those of the standard. The comparisons were made five times within each metre for every interval of 93 centimetres; the first and last divisions were simultaneously read off by two observers, the readings being repeated by changing the observers; the force used in pushing in the wedge introduced, of course, a small personal error into the operation.

The comparisons with the standard metre rod—which extended from June 1877 to February 1881—showed an expansion of 4·4 mikra[1] per metre and Centigrade,[2] a result which agrees satisfactorily with the expansion coefficients of wood previously determined. Working with these coefficients the staff was found to have its right length at 0° Centigrade.

The comparisons of the staff by the standard rod and the wedges were made in three periods, viz.:—

from 18th July to 15th September 1879,
„ 3rd June „ 2nd July 1880,
„ 17th July „ 5th September 1880.

The greatest differences recorded in each period were 52, 53, and 52 mikra respectively, due partly, no doubt, to inaccurate readings, &c. The Author concludes from these experiments that changes in length of staff under every condition of weather, independent of heat, only amount to $\frac{1}{20}$ millimetre per metre. It should, however, be noticed that special care was taken in the construction of the Dutch levelling-staves.

E. H. C.

On the Extension of the Paris Meridian to the Sahara.

By Hr. Pattenhausen.

(Zeitschrift für Vermessungswesen, June 1881, pp. 247–257.)

After reviewing the progress made in measuring arcs of meridian in Europe, commencing with Picardi's arc in 1669, whose amplitude was only 1° 23′, to that completed in 1860 by the junction of

[1] A mikron = 0·001 millimetre.
[2] *Sic* in orig. Probably per metre and degree Centigrade is meant.

Digitized by Google

the English and French Surveys, whose amplitude was 22° 10′, the Author proceeds to describe the junction of the Algerian with the French and Spanish Surveys, by which the largest arc yet attempted, viz., of 27°, has just been measured.

For the Algerian triangulation three base lines were measured—one at Blidah, another at Bona, and a third at Oran—with an improved form of Delambre's apparatus, where the interval between two successive rod-lengths is found by a slide fitted with a vernier. The whole network comprised eighty triangles of the first order, the Blidah base being used for the calculations, the two others being merely bases of verification. The results are surprising, as the calculated differed from the measured lengths by + 0·12 metre in the Bona base, and by − 0·34 metre in the Oran base.

For joining the Algerian with the Spanish triangulation across the Mediterranean, the following mountain tops were selected:—Mulhacen (3,550 metres) in the Sierra Nevada, and Tetica (2,081 metres) in Murcia on the Spanish side, and Filhaoussen (1,137 metres), and McSabiha (584 metres) in Africa. The same instruments were used on both sides, 16½-in. theodolites, with telescopes of 30 times magnifying power, and alidades carrying four microscopes, by which centesimal seconds could be read directly. Every angle was taken in two positions of the telescope, and repeated forty times in each.

For signalling, the Heliostat was originally used, with a mirror, first 4 inches and afterwards 12 inches square, but being found useless on account of the sea-fogs prevalent at that season, recourse was had to the electric light. Two different kinds of apparatus were used for flashing the light, "Mangin's Projector" and the "Collimator." The first is an aplanatic mirror of 19½ inches diameter, with a focal length of 24 inches made up of a convex-concave diverging lens, of which the upper lens is silvered. A Serrin's lamp is used, with carbon of 6 millimetres thickness.

The "Collimator" consisted of an object lens of 8-inch diameter and 24 inches focal length, and a lens system which concentrated the light of an electric lamp in the focus of the object glass, so that the rays leave it as a bundle of parallel rays. The lamp had carbons only 5 millimetres thick, but the results showed that this smaller apparatus was nearly as good as the "Projector," while its working was simpler and quicker.

To generate the current two kinds of Gramme's machines were used, the one being of 1¼-HP. with a speed of nine hundred revolutions a minute, the other of 1½- to 1¾-HP., and a speed of one thousand three hundred revolutions a minute.

The necessity for using electric light greatly enhanced the difficulties of the work, owing to the transport of the requisite stores; climatic conditions also greatly interfered, so that the actual time for work was reduced to about six weeks. On 20th August 1879 all was in readiness, but fog prevented any signalling till 9th September, after which date observations were continuously carried on till the middle of October. In the result the greatest error in

Digitized by Google

any one triangle was only 0·62 second. The side Filhaoussen-McSabiha was computed as a check from two independent series —once from the Madrid base, and next from the Oran base—with a disagreement of only 0·66 metre.

On the completion of the above work, the great Polygon of Longitude Paris-Madrid-Marseilles-Algiers had to be closed, and the period from 18th October till 16th November was devoted to this undertaking. All the lengths except that between Algiers and Madrid were found in 1874 by the aid of the electric telegraph, but as no cable connects these two places, the apparatus, already used for the geodetical measurements, was brought into requisition, the stations McSabiha and Tetica being fitted up as observatories. On fine evenings local time was found at each station by four series of observations, each series comprising one circumpolar and twelve equatorial stars. Liais' method of rhythmic signalling was adopted, because the personal equations of the observers were thereby found to be much smaller, a "collimator" (similar to the one before described) being used at both stations for flashing the light. Every two seconds the light was eclipsed during one second by a small perforated disk, moved by the anchor of an electro-magnet, the moment of its disappearance being recorded automatically. As the observer at the distant station also noted this disappearance in the same way as a star-transit, the difference in longitude between the two places could easily be ascertained from a comparison of their local time.

The work was carried on as follows: at a fore-concerted time both stations flashed signals unintermittently for half-an-hour, then one stopped, as a sign that all was ready, whereupon the other (say, Tetica) flashed forty signals, and then stopped, while McSabiha sent forty signals in the same way. A complete exchange of signals for one evening amounted to six hundred and forty signals in all.

The lengths found by rhythmic signalling compared well with those fixed by electric telegraph, the probable error in any length not exceeding one hundredth part of a second in time.

E. H. C.

On Graphical Integration as applied to the Statics of the External Forces upon the Simple Beam.

(Allgemeine Bauzeitung, 1881, p. 24.)

If in a rectangular system of co-ordinates the abscissæ (x) correspond with the longitudinal measurements of a beam, and the ordinates (y) with the intensity of the load at any point, the load on the beam is represented by a curve. The statical moment of an infinitely small element of the load with regard to a given axis, for example, to the y axis of the system is then

$$x \cdot F''(x)\, dx,$$

where $F''(x)$, *i.e.* a function of x is the ordinate, F'' indicating the

Digitized by Google

law of dependence, *i.e.* the curve itself. If then the sum of moments of all loads between $x = a$ and $x = b$ is required, this will be

$$M = \int_{x=a}^{x=b} x\, F''(x)\, dx.$$

In case of moments of inertia the equation will be

$$M_i = \int x^2\, F''(x)\, dx.$$

The object of the Paper is to show a graphical solution of these and similar equations, and to apply the method to the following cases of the loading of a beam:—

a. Permanent continuous load.
b. Moving ,, ,,
c. Moving concentrated load.
Determination of greatest moments and vertical forces
d. Moving load, partly concentrated, partly continuous.
Determination of greatest moments and vertical forces.
e. Indirect loading (*i.e.* by means of cross girders).

In the introduction the principles of graphical derivation and integration, upon which is based the solution of such equations as the above, is demonstrated somewhat as follows:—

Graphical Differentiation.—Let F be the curve whose equation is—

$$y = F(x),$$

and $P_1\ P_2$ two points in the curve, $p_1\ p_2$ their projections on the X-axis of the system, and $\pi_1\ \pi_2$ those on the Y-axis, O the origin of the system, so that $O\,p_1 = \pi_1\,P_1 = x_1$ and $O\,\pi_1 = p_1\,P_1 = y_1$, &c., then the equation $y = F(x)$ defines the position of the points $P_1\ P_2$, &c.; but there is another way of defining them, and that is by the system of tangents which envelop the curve F. If parallels to these tangents are drawn through a pole O′ (in the X-axis to the left of O, O′ O being the pole distance H) and their intersections with the Y-axis are $\mu_1\mu_2$, the rays $O_1\ \mu_1$ and $O_1\ \mu_2$ being parallel with the tangents at P_1 and P_2, and if the points μ_1 and μ_2 are combined with points $p_1\ p_2$, then a new curve F^1 is the result, whose points $P_1^1\ P_2^1$ have $\mu_1\ \mu_2$ for their vertical projections, and $p_1\ p_2$ for their horizontal projections. The relation of this new curve F^1 to the curve F is obviously—

$$\frac{dy}{dx} = \tan x = \frac{O\mu}{H},$$

and since $O\mu = p\,P^1 = y^1$

$$\frac{dy}{dx} = \frac{y^1}{H}$$

is the equation of the c

Digitized by Google

or making H = 1—

$$y^1 = \frac{dy}{dx} = F^1(x),$$

that is to say, the ordinates of the curve F^1 are the first differentials of the function $F(x)$. The second differentials would be derived from the curve F^1 in the same way as F^1 was derived from F.

Graphical Integration.—If the curve F^1 is given by its equation

$$y^1 = \frac{dy}{dx} = F^1(x),$$

and this equation is to be solved, *i.e.* a curve F to be found whose x and y are in the relation to each other indicated by the equation, then the latter furnishes only the directions of the tangents, and another condition (the constant of integration) must be supplied in order to define the position of the curve. Such a condition could be made for example by the requirement that the curve should go through a given point.

To find the curve F itself, the enveloping tangents must be drawn parallel to the lines $O^1\mu_1$ $O^1\mu_2$, &c. The first can be drawn but not the second until its intersection with the first is known. In order to find this it is necessary to assume that in the curve F^1 the small elements $P_1^1 P_2^1$ are straight lines, *i.e.* that their equation is

$$y^1 = \alpha x + \beta.$$

Integrating this equation the equation of a parabola is obtained, viz., $y = \frac{1}{2}\alpha x^2 + \beta x + \gamma$, from which follows that the elements $P_1 P_2$ of the curve F are pieces of parabolas whose axes have the direction of the ordinates. The intersection of the two tangents at the ends of the pieces therefore lies—horizontally measured—in the middle between P_1 and P_2. This rule enables all the tangents of F to be drawn in succession. If the pencil of rays $O^1\mu$ is drawn directly in accordance with the intermediate points in F^1, a polygon will be the result, which is inscribed within F.

Graphical measurement of areas.—Given two curves F_1^1 and F_2^1. The area is to be measured which is enclosed by them and by two given ordinates.

A third curve is constructed whose ordinates are $F_2^1(x) - F_1^1(x)$. This curve is integrated in the manner already shown, and the differences of the terminating ordinates of the new (the fourth) curve is the area required.

Graphical solution of the equation—

$$y'' = \frac{d^2y}{dx^2} = F''(x).$$

According to the method already known, the first integral curve

Digitized by Google

is constructed which goes through the point whose co-ordinates are x_a and $F^1(x_a)$, thus corresponding to the equation

$$y^1 = \frac{dy}{dx} = F^1(x) + \text{const.}$$

Integrating a second time by the same method a new condition has to be made, viz., that in the new curve F, a given $F(x_a)$ corresponds to a given x_a. This determines the constant for the second integration. If in the two integrations the pole distances have been assumed to be H_0 and H, the length $F^1(x) - F^1(x_a)$ is reduced in the proportion $\frac{1}{H_0}$ and $F(x) - F(x_a)$ in the proportion $\frac{1}{H_0 H}$.

Having introduced these methods of differentiating and integrating at the outset, the Author proceeds with the solution of the above-mentioned equation—

$$M = \int_{x=a}^{x=b} x F''(x)\, dx.$$

This is done by putting

$$\frac{d^2y}{dx^2} = F''(x),$$

and integrating twice, *i.e.* constructing the integral curves F^1 and F.

If in the first integration the pole distance is made = 1, and in the second = H, and if the tangents on the curve F at its two terminal points intersect the axis of moments (conveniently the Y-axis of the system) in points α and β the following relation obtains:—

$$M = \int_{x=a}^{x=b} x F''(x)\, dx = \overline{\alpha\beta}\, H,$$

for it can be shown that such portion of the length $\alpha\beta$ as is cut off by the intersections of two consecutive tangents, viz. the length $\tau\tau_1$ is

$$\overline{\tau\tau_1} = \frac{x F''(x)\, dx}{H}.$$

Graphical solution of the equation—

$$M = \int_{x=a}^{x=b} x^2 F''(x)\, dx.$$

Digitized by Google

This is done by putting $\frac{d^2 y}{d x^2} = F''(x)$ and integrating this equation twice, *i.e.* constructing the integral curves F^1 and F. The area of the surface enclosed by the curve F, by the two tangents at its terminal points, and by the axis of moments, and then multiplied with twice the pole distance, is the total moment of inertia. Here again is

$$\overline{\tau\tau_1} = \frac{x F''(x) d x}{H},$$

hence

$$\overline{\tau\tau_1} \frac{x}{2} = \frac{x^2 F''(x) d x}{2 H},$$

of which equation the left side represents the area of one of the small triangles of which the area of the surface is composed; therefore the sum of all these triangles multiplied with 2 H is the integral in question.

The Paper then treats of the problems mentioned at the beginning of this abstract in detail, and with numerous diagrams, in a manner not differing much from treatments already known.

M. A. E.

Self-recording Indicator of the Elastic Extensions of Loaded Bars.

By Dr. W. FRÄNKEL, Dresden.

(Der Civilingenieur, 1881, col. 249.)

The instrument can be attached to any member of an existing structure, and by means of a diagram will permanently record the behaviour of the piece during the passage of any travelling load. It is sufficiently delicate to read to ·003 of a millimetre, which would be the total extension of an iron bar 1 metre long under a load of 6 kilograms per square centimetre.

It consists essentially of a hollow cylindrical bar of considerable length, one end of which (furnished with a ball-and-socket joint) is clamped to the piece to be tested, while the other bears against the short arm of a bent lever pivoted on a sole piece also clamped to the piece. By means of a multiplying arrangement this lever rotates a cylinder, the axis of which is perpendicular to the axis of the bar, and round which a sheet of paper is wrapped. A pencil pressed steadily against the paper would therefore record any alteration of the length of piece between the two clamps as a straight line; but by means of clockwork a motion is imparted to the pencil parallel to the axis of the cylinder, and the point therefore, under the combined motions, traces out a curve, the abscissæ of which (on a line parallel to the axis of cylinder) are proportional to the time, and the ordinates of which are proportional to the extensions caused.

Digitized by Google

An ingenious arrangement prevents backlash between the different pieces in gear, whereby great steadiness of motion is secured. This is important, as it is essential to provide for frequent alternations of the motion. Of each pair of wheels gearing together, one is divided into two equal thicknesses, thus consisting practically of two precisely similar disks in contact with each other on the same axis. A spring attached to one of these acts on the other, so that when the first disk is in gear and driving, the teeth on the second disk are in contact with the opposite faces of the teeth on the driven piece, and therefore ready at any instant to reverse the motion of this.

The Paper is illustrated with a number of diagrams taken on various existing bridges, and the Author points out they show that the maximum strain in practice does not always agree with what might be expected from the ordinary method of calculation. From the numerous examples given, the following are selected as illustrating the results furnished by the instrument:—

No. 1. A skew bridge with girders of the Whipple-Murphy type, each of six bays, on the Altstadt and Friedrichstadt Railway, Dresden.—The two central bays are counterbraced, and an instrument was attached to each angle-iron of the bottom boom of the second bay from the right (*i.e.*, one was on the right and the other on left of central plane of girder).

The load passed over the bridge from left to right. The stress was found to be greater in the outer-angle iron than in the inner, and to vary with the distance from central plane, the increase or diminution being about 0·2 per cent. of the mean value for each millimetre of distance. Thus the extreme fibres of the outside angle-iron were extended 18 per cent. more, and the extreme fibres of the inside angle-iron 18 per cent. less, than the mean extension, and the Author concludes that, in addition to a uniformly-distributed tensile stress over the bottom boom, there was a bending stress amounting on the extreme fibres to ± 26 kilogrammes per square centimetre. The bending was convex outwardly from the centre line of railway, and appeared to be due to the obliquity of the bridge, in consequence of which the two main girders are unequally loaded. When the indicators were attached to the diagonal of the same bay, the diagrams showed that a bending took place perpendicular to the plane of the girder convex outwardly, and a bending in that plane convex upwardly; the upper layer of fibres being extended 9 per cent. more and the lower 9 per cent. less than the mean.

No. 2. Whipple-Murphy girder bridge over the Elbe at Meissen. Span, 174 feet, with a double system of triangulation, of sixteen single or eight double bays, 24 feet deep in the centre and about 19 feet deep over the abutments.

The indicators were fixed to the four first diagonals from the left, and the load (two locomotives with tenders) came on from the right. The theoretical strains corresponding to a given position of the load (the leading wheel over the foot of the fourth diagonal),

Digitized by Google

calculated by the ordinary method of omitting the alternate diagonals so as to reduce the system to a single triangulation, are proportionally given by

$$\frac{S_4}{f_4} : \frac{S_2}{f_2} = 1{,}169, \text{ and}$$

$$\frac{S_3}{f_3} : \frac{S_1}{f_1} = 1{,}222,$$

where S is the stress on and f the area of each bar, the suffixes denoting the particular bar. The actual extensions (Δ) as recorded by observation were proportionally

$$\frac{\Delta_4}{\Delta_2} = 1{,}234$$

$$\frac{\Delta_3}{\Delta_1} = 1{,}779$$

The proportional difference between the calculated and observed values in the fourth and second diagonals is therefore

$$\frac{1{,}234 - 1{,}169}{1{,}169} \cdot 100 = 5\tfrac{1}{2} \text{ per cent.}$$

and for the third and first diagonals

$$\frac{1{,}779 - 1{,}222}{1{,}222} \cdot 100 = 46 \text{ per cent.}$$

Similarly when the leading wheel comes to the foot of the third diagonal, the proportional difference between the calculated and observed values for the diagonals 1 and 3 amounts to 44 per cent. of the former. The Author draws the conclusion that the usual method of calculating the stresses on the diagonals of a compound girder by resolving it into independent systems may lead to great errors in practice.

T. H. E.

On the Effect of Prolonged Stress upon the Strength and Elasticity of Pine Timber. By Prof. R. H. Thurston.

(Journal of the Franklin Institute, vol. cxii., 1881, p. 161.)

This is a further contribution from Professor Thurston respecting the behaviour of timber under stress.[1] It was shown by Haupt forty years ago that timber may be injured by a prolonged stress

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxiii., p. 339.

Digitized by Google

far within that which leaves the material uninjured when the test is for a few minutes only, and Professor Thurston has confirmed this result by an extended series of experiments, partly described in detail in the present Paper.

A selected 12-inch × 4-inch × 24-feet well-seasoned plank, the history of which was known, was cut into test strips. The modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2}$, was usually 11,000 to 12,000, and the modulus of elasticity from 2 to 2¼ millions. When kiln-dried both moduli were considerably increased. For the purpose of testing the effect of prolonged stress, twelve pieces were shaped rather more than 1 inch square, and loaded at the centre of 40-inch bearings. Three of these broke respectively with loads of 345, 380, and 410 lbs., so that the fair average ultimate strength of the specimens might be taken at 375 lbs. The remainder were loaded in sets of three, with 250 lbs., 300 lbs., and 350 lbs., or about 60, 80, and 95 per cent. of their probable maximum strength. The whole set of bars loaded most heavily broke within two days; the second set in periods ranging from 3½ days to a month; and the lightly loaded bars in periods ranging from 6,000 to 11,100 hours, or 15 months after the application of the stress.

Comparing the ultimate deflection of the several sets of bars, it was seen that the average under the quick test was about 1·8 inch, whilst under a prolonged load of 95 per cent. the rods broke at a deflection of 2·4 inches; under 80 per cent. at 3 inches; and under 60 per cent. at something less.

The Author is of opinion that a load of 50 per cent. would probably have been sustained an indefinite period, or until decay had weakened the timber. Applying a factor of safety of 2, there is obtained as a safe factor, based on the ordinary test, 4. The Author would, in the light of what is now known, always use a factor of safety of at least 5 under absolutely static load; and when the uncertainties of ordinary practice as to the exact character of material, and especially where shakes and the impact of live load were to be considered, would make the factor not less than 8, and for much ordinary work 10.[1]

B. B.

---

[1] It is necessary to remember that Prof. Thurston is dealing with selected specimens of exceptional strength, and that a factor of 10 with his modulus would for a given load give a beam of the same size as a factor of 5 with the modulus usually adopted in this country, which has been derived from experiments on large scantlings, and includes the effects of shakes.—B. B.

Digitized by Google

On Variations in the Limit of Elasticity and in the Modulus of Elasticity of Various Metals. By Prof. J. BAUSCHINGER.

(Der Civilingenieur, 1881, col. 289.)

The Paper contains numerous and extensive tables, the results of various experiments made on bars of weld-iron,[1] ingot-iron, Bessemer steel and bronze, and on plates of copper. In Dingler's Journal, vol. 224, the Author proved the following law to hold in the case of Bessemer steel:—"By stretching the metal beyond its elastic limit, the range of the elasticity is increased not only during the time for which the load is applied, but also for a considerable period of repose after the stretching (*i.e.*, while the bar is unloaded); such period extending to one or several days, and by this means the elastic limit itself can be raised to a limit greater than the load which caused the original extension." There can scarcely be a doubt that this is due to the effect of what has long been known as "secondary elastic action," and it agrees with some results obtained by Wöhler, and published in Erbkam's "Zeitschrift für Bauwesen" as far back as 1863. In continuing his experiments on the subject, the Author proposed to himself two questions:—

1. What influence the length of the period of repose, following the extension of the bar under a given load, had upon the magnitude of the consequent increase of the elastic limit? and,
2. Whether any and what alteration of the modulus of elasticity was thereby brought about?

The testing machine used permitted of variations in the length of the bars to be read to the ten-thousandth of a millimetre; and since the parts of the bars tested were all originally 15 centimetres long, this corresponds to the variation of the 1,500,000th part of the length, and the Author claims that the use of such delicate measurements must lead to a clearing up of the views held as to the limit of elasticity, the definition of which became uncertain as soon as it was known that permanent alterations of length were produced by relatively light loads.

Measurements with the apparatus used, show that in materials known to be elastic, such as wrought iron, steel, wood, &c., Hooke's old law "*ut tensio sic vis*" (*i.e.*, the proportionality of the alteration of length to the load which produces it), always holds strictly within a certain limited range. Once this range—which the Author proposes to call the limit of proportionality—is passed, the extensions become gradually greater and greater under successive equal increments of load. With many materials, especially weld- and ingot-iron and the softer kinds of steel, a second noteworthy point is reached by a gradual increase of the load above the limit of proportionality. The extension is gradual under successive equal increments of load, until this point is reached, but then suddenly

[1] This nomenclature is used as an attempt to follow out the classification of wrought iron recently proposed by Prof. Bauschinger, and to some extent adopted in Germany.

Digitized by Google

becomes very rapid—so rapid that the image of the scale on which the extension is measured passes out of the field of view of the telescope, so that a reading is no longer possible. Under a greater load than that corresponding to this limit, the scale does not come back into the field of the telescope till after a long interval, of at least several hours, of quietude; *i.e.*, the secondary elastic effort has to act for several hours, and in some cases with high loads for several days, in diminution of the effect produced at once by application of the load. This point may be called the "drawing-out-limit,"[1] and the analogous point in case of compression the "bulging-limit." The total effect may be exhibited graphically thus: If the successive loads are set off as abscissæ along any line, and corresponding ordinates are drawn proportional in length to the extensions caused by the loads, a curve drawn through the extremities of the ordinates may be called the stress curve. Within the limit of proportionality this curve will be (at least approximately) a straight line, but beyond it will gradually become more and more curved, while at the "drawing-out limit" the curve will show a more or less sharply defined bend or angle.

The Author discusses the two following recently proposed definitions of the limit of elasticity. One by Wertheim: the stress under which the permanent extension caused by it amounts to the twenty-thousandth part of the original length; the other by Styffe: if a bar of iron or steel is gradually stretched under a series of loads, the first being so small as to cause no permanent set, each acting for the same number of minutes, and which are so increased that each increment is the same percentage of the whole load, then the elastic limit is the stress under which, acting for the prescribed time, there is a permanent extension bearing to the length of the bar the ratio of 0·01 of the ratio of the increase of weight to the whole load. Under Wertheim's definition the permissible extension in an original length of 15 centimetres would be 0·0075 millimetre, but the tabular results of the experiments show that, with ordinary materials, the limit of proportionality is generally passed long before this extension is reached, and frequently the "drawing-out limit" also, when it exists. In Styffe's definition time is made an element, which in the Author's view should not be, and he shows by an example that the definition may lead to a stress being taken far above the "limit of proportionality," and maintains in consequence that such arbitrary definitions are inadmissible, and that the limit of elasticity ought to be the "limit of proportionality," as tested for each particular material. A consequence of this would be that materials such as cast iron and stone would simply have no elastic limit.

The time which is allowed to intervene between successive loadings of the bar appears to have considerable influence on its behaviour; as the following figures selected from the Tables will show:—

[1] It appears to correspond with what Prof. Kennedy has called the "breaking-down limit."

Digitized by Google

A. A Bar of Weld-Iron.

	Kilograms per Square Centimetre. (0·00635 ton per square inch.)			
	Limit of Elasticity.	Stretch Limit.	Load Removed.	Mean Modulus of Elasticity.
First time of testing	1,414	1,919	2,222	2,060,000
Second testing, immediately following first	1,010	2,222	2,828	1,964,000
Third testing, immediately following second	1,048	2,935	3,354	1,946,000
Fourth testing, immediately following third	1,087	3,478	..	1,937,000

The maximum stress produced a permanent extension of 41 millionths of the original length.

B. A Precisely Similar Bar.

	Kilograms per Square Centimetre. (0·00635 ton per square inch.)			
	Limit of Elasticity.	Stretch Limit.	Load Removed.	Mean Modulus of Elasticity.
First time of testing	1,610	2,113	2,213	2,060,000
Second testing, eighty hours after the first	2,240	2,444	2,851	2,026,000
Third testing, sixty-eight hours after the second	2,485	3,106	3,313	1,985,000
Fourth testing, sixty-four hours after the third	2,982	..	3,408	2,018,000

And under this maximum stress the elongation was 18 millionths of the original length.

From the series A it will be seen that, when no appreciable interval occurs between the loadings, the limit of elasticity is diminished at the second application, but afterwards gradually increases, and that the "drawing-out limit" increases throughout. From the series B it will be seen that, with considerable intervals of repose, both limits are steadily raised throughout. This appears to hold generally.

T. H. E.

Digitized by Google

Experimental Proofs of some new Formulæ for the Torsion of Prismatic Bodies. By Prof. J. BAUSCHINGER.

(Der Civilingenieur, 1881, col. 115.)

The Author commences with nearly a column of explanation of the symbols used, and then applying his formulæ to five bars of the following sections: (1) circular; (2) elliptical, with axes in ratio of 1 : 2; (3) square; (4) rectangular, with sides in ratio of 1 : 2; (5) rectangular, with sides as 1 : 4, he deduces the following equation:—

$$d_1 : d_2 : d_3 : d_4 : d_5 = 1 : 1{\cdot}25 : 1{\cdot}13 : 1{\cdot}40 : 9{\cdot}1,$$

where d_1 is the amount of rotation which a cross section of the circular bar takes relatively to a parallel one at a fixed distance from it under the action of a given force; d_2 is the corresponding amount in the bar of elliptic section under the same force, and so on.

It should be noticed that the dimensions of the bars are so adjusted that the areas of Nos. 1, 2, 3 and 4 are equal to each other, and the area of No. 5 (sides as 1 : 4) half either of the others.

By an approximate formula the above equation becomes—

$$d_1 : d_2 : d_3 : d_4 : d_5 = 1 : 1{\cdot}25 : 1{\cdot}05 : 1{\cdot}31 : 8{\cdot}9.$$

Experimental results were obtained as follows:—Five pairs of bars of cast iron, each 100 centimetres long and of the above sections, were twisted in a Werder's testing machine as explained in the Author's already published "Essais de Résistance." The cross sections, the relative rotations of which were measured, were 50 centimetres apart, and the rotation was measured on the arc of a circle of 350 centimetres radius (or rather on the tangent to such a circle) by means of telescopes, special precautions being taken to eliminate errors and secure exact readings. Tables of results are given, from which it appears that taking the circular bar as the standard of comparison, experiment agrees well with theory in the case of the bar of elliptic section; but the agreement is not so close as could be desired with the square and rectangular bars. With them the observed rotations are greater than the values given by the first of the above equations, and harmonise still less with those of the approximate equation, which are smaller than those obtained from the rigorous formula.

Reference is made in the Paper to experiments on torsion, the particulars of which are given in Tables 122 to 147 of the "Essais de Résistance" already referred to. These experiments were made on bars of Siemens-Martin steel of various degrees of hardness, of Bessemer steel similarly varying, and of iron both granular and fibrous in texture. The bars were 660 millimetres long, and circular or square in section, the diameter or side being in each

Digitized by Google

case 10 centimetres. By the formula the relative amount of rotation of two bars of the same material should be given by

$$d_1 : d_3 :: 1 : 0{\cdot}698,$$

and though there is some discrepancy between the experimental and theoretical results in individual cases, yet the average of thirteen pairs of bars gives,

$$d_1 : d_3 :: 1 : 0{\cdot}696.$$

The thirteen values range between

$$1 : 0{\cdot}633 \text{ in iron bars of fine grain,}$$
$$\text{and } 1 : 0{\cdot}747 \text{ in Bessemer steel bars.}$$

A further proof of the formulæ is obtained by deducing from them the modulus of shearing elasticity (η), and comparing the results with those obtained from the formula,

$$\eta = \frac{\epsilon}{2(1+\mu)},$$

where ϵ is the modulus of tensile or compressive elasticity, and μ is the ratio between the sectional contraction or dilatation, and the increase or diminution of length produced by direct tensile or compressive stresses. Tables of values are given, and they agree as well as could be expected when the minute quantities to be measured are considered, and it is worthy of notice that the ratio μ is practically independent of the form of the cross section.

A formula given by the Author for the maximum shearing stress produced in a section by torsion, cannot be proved directly, since it is impossible to measure the stress at any precise spot. The method adopted was to increase the moment of torsion till rupture ensued, and to compare the corresponding values of maximum stress as given by the formula (which may be called the "strength of torsion") (*torsions festigkeit*), in the case of bars of different sections. As might be expected, the form of the cross section had in this case very great influence on the result; the section of greatest strength being the circular, and next to it the square, the least favourable being the rectangular with sides as 1 : 4. The proportional figures for the maximum stress produced by an equal moment of torsion were,

$$1 : 1{\cdot}414 : 1{\cdot}269 : 1{\cdot}795 : 2{\cdot}539,$$

the order of the bars being that previously given.

The Author proposes to make further experiments on the torsion of bars of similar sections but of varying dimensions.

T. H. E.

Digitized by Google

Experiments on the Strength of Wrought Iron and Steel at High Temperatures. By C. R. Roelker.

(Journal of the Franklin Institute, vol. cxii., 1881, p. 241.)

This Paper contains no original matter, but is an interesting summary of previous investigations. Kollmann's experiments at Oberhausen included tests of the tensile strength of iron and steel at temperatures ranging between 70 and 2,000 degrees Fahrenheit, and the mode of conducting these tests is detailed in the Paper. Three kinds of metal were tested, viz., fibrous iron having an ultimate tensile strength of 52,464 lbs., an elastic strength of 38,280 lbs., and an elongation of 17·5 per cent.; fine-grained iron having for the same elements values of 56,892 lbs., 39,113 lbs., and 20 per cent.; and Bessemer steel having values of 84,826 lbs., 55,029 lbs., and 14·5 per cent. The mean ultimate tensile strength of each material expressed in per centum of that at ordinary atmospheric temperature is given in the following Table, the fifth column of which exhibits, for purposes of comparison, the results of experiments carried on by a committee of the Franklin Institute in the years 1832–36.

Temperature Fahrenheit.	Fibrous Wrought Iron.	Fine-grained Iron.	Bessemer Steel.	Franklin Institute.
°	Per Cent.	Per Cent.	Per Cent.	Per Cent.
0	100·0	100·0	100·0	96·0
100	100·0	100·0	100·0	102·0
200	100·0	100·0	100·0	105·0
300	97·0	100·0	100·0	106·0
400	95·5	100·0	100·0	106·0
500	92·5	98·5	98·5	104·0
600	88·5	95·5	92·0	99·5
700	81·5	90·0	68·0	92·5
800	67·5	77·5	44·0	75·5
900	44·5	51·5	36·5	53·5
1,000	26·0	36·0	31·0	36·0
1,100	20·0	30·5	26·5	..
1,200	18·0	28·0	22·0	..
1,300	16·5	23·0	18·0	..
1,400	13·5	19·0	15·0	..
1,500	10·0	15·5	12·0	..
1,600	7·0	12·5	10·0	..
1,700	5·5	10·5	8·5	..
1,800	4·5	8·5	7·5	..
1,900	3·5	7·0	6·5	..
2,000	3·5	5·0	5·0	..

Comparing Kollmann's results with those of Fairbairn, Styffe, and the British Admiralty, the Author finds that the former differ from the latter in respect of there being found no increase of strength at temperatures higher than the ordinary atmospheric temperatures.

B. B.

Digitized by Google

On the Determination of the Quality of Iron and Steel.

By Prof. Lud. Tetmajer.

(Eisenbahn, Zurich, 15th Oct. 1881, p. 92.)

In a previous article on the same subject[1] the Author gave his reasons for objecting to the method of determining the quality of iron and steel as recommended by the Commission of the German Railway Union;[2] namely, by means of the breaking strains and the contraction, and substituted for it the working capacity, *i.e.*, the product of tensile breaking strain into the elongation.

$$a = \eta \beta \lambda$$

where η is constant for a certain kind of metal. Further experiments by the Author have confirmed the constancy of η, and have shown that even for different brands of the same kind its variations are of no practical importance; the different brands at present in the market can therefore be treated together in groups on the basis of the working capacity.

In the above equation a determines the class of quality of a kind or group, η the kind of the material. Consequently, $\frac{\text{minim. } a}{\eta}$ is constant for a certain class, and this constant

$$c = \beta \lambda$$

is the coefficient determining a class, β being given in ton per square centimetre, and λ in percentage of a given length of bar. The law of dependence of β from λ is expressed by a hyperbola, whose asymptotes are the axes of the system, and the different classes of quality can be distinguished from each other by pieces of hyperbolas.

Availing himself of the results arrived at by prominent experimentalists, and having regard to the interests of both railway companies and ironmasters, the Author has worked out the following classification:

A. Puddled iron (four classes).

I.	quality,	$c = 68$	ton	per cent.
II.	,,	$c = 48$	,,	,,
III.	,,	$c = 34$	,,	,,
IV.	,,	$c = 24$	,,	,,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxvi., p. 439.
[2] *Ibid.*, vol. lxv., p. 436.

Digitized by Google

B. Cast malleable iron or steel (one class).

c = 93 ton per cent.

[For example, iron of a breaking strain = 3,200 kilograms per square centimetre, and an elongation of 12 per cent., has a c = 38·4, and would accordingly rank in class III.—Ed.]

The limiting figures for the various classes would have to be agreed upon from time to time, although it is not likely that those of group A. will be greatly modified. The results of experiments with this material, when plotted on a system of co-ordinates β and λ, are spread very evenly over the range of the above four constants; the results from material of the group B., on the other hand, lie much closer together when plotted on the system, and a hyperbola c = 93 can be drawn easily; in such a way that the great bulk of the plottings lies above, and not very far above it.

Graphical interpretations of the same experiments on the basis of breaking strength and contraction did not bring to light any rule, while the grouping of the plottings according to β and λ seems to confirm the correctness of the Author's method. The curve c = 93 is, in the opinion of the Author, still too low; but it is higher than the lines proposed by the German ironmasters, which are so low that, according to them, a consumer would be obliged to accept almost anything that is produced.

The conditions of specifications with reference to quality of metal would have to be stated in the following forms (given as an extract):—

Prime rivet and bolt iron,

Min. tensile strength β = 3·8 ton per sq. centimetre.
Coefficient of quality c = 68 ton per cent.

Round bar iron for machinery and bridges.

Min. tensile strength β = 3·6 ton per sq. centimetre.
Coefficient of quality c = 48 ton per cent.

Cast-steel rails.

β = from 5·2 to 6·4.
c = 93.

Cast-steel tires.

β = from 4·6 to 5·5
c = 93.

Cast malleable iron boiler-plates.

β = from 3·7 to 4·8.
c = 93.
&c.

M. A. E.

Digitized by Google

The Great Structures erected in Italy during the last twenty years.

By C. Clericeti.

(Conferenze sulla Esposizione Nazionale del 1881, p. 179.)

The Author chooses the bridges of iron and stone erected during the last twenty years as the structures which best exhibit the progress of engineering science, and he compares these modern bridges with those built by the Romans. The characteristics of these latter are grandeur, massiveness, and durability; of the former, lightness, economy, and rapidity of construction.

The Po between Pavia and the sea was never bridged by the Romans, but during the last twenty years four bridges have been built over it. The lengths of these bridges are 577, 762, 427, and 400 metres, 1,900, 2,600, 1,399, and 1,312 feet respectively, the spans varying from 213 to 250 feet. They are all girder bridges, supported on piers founded at depths of from 60 to 70 feet below highest flood level, and formed of iron cylinders sunk by the hydraulic process.

To show the difference between the ancient and modern systems of construction the Author compares the Roman bridge across the Danube, one of the boldest of their works, with the modern structures on the Po. The former—1,207 metres (3,960 feet) in length—had twenty-one wooden arches of 50 metres (164 feet) span; and the piers—founded on a masonry platform extending right across the river bed—had a thickness of 17·7 metres; while the piers of the latter, though 28 metres high from the foundation, are less than 3 metres thick at the top. The ancient piers had six times the thickness required for a modern girder bridge, and three times what would now be allowed for masonry arches of 50 metres span. The same immense piers were built throughout the middle ages; the old bridge at Verona, for instance, with two arches of 28·54 metres and 48·70 metres (93½ and 160 feet), has a pier 12 metres thick, though only 3·50 metres high.

The Author proceeds to point out the superiority of the modern system of long spans and narrow piers, in leaving the channel free for navigation and the discharge of floods, and avoiding the scouring action caused by obstacles to the natural flow. In some cases old bridges have so impeded the flow as to cause serious inundations above bridge.

The ironwork of the great bridges over the Po was imported from abroad, but the Italians are now constructing their own, some spans of 75 metres (246 feet) having been already built, and others of larger dimensions, up to 100 metres, will shortly be commenced.

The Author states that, with few exceptions, only one type of bridge—the lattice-girder—is constructed in Italy, and regrets that little encouragement is given to improvements in design. He

Digitized by Google

mentions a few arched bridges, among them being that over the Celina torrent,[1] which he considers one of the best examples.

The Author proceeds to discuss the subject of the incalculable strains to which bridges are liable; from the points of support not being knife edges, as theory supposes; from the variations in cross sections; from the vibration caused by passing trains, &c. Airy[2] attempted to ascertain the strain in a bar of iron from its musical note, but the result was not satisfactory. Better results are obtained by instruments for measuring the contraction and elongation of bars during strains, such as the apparatus of Dupuit and Manet in France, and Castigliano's multiple micrometer, which the Author describes.

The experiments made with Dupuit's apparatus upon all kinds of girders show that the actual maximum strains are in general less than the calculated, particularly in arches and in the horizontal members of straight girders.

Iron bridges are also exposed to danger from corrosion, but the Author states that Mallet's experiments proved that an iron bar 6 millimetres (0·238 inch) in thickness would not be destroyed in less than 700 years.

The Author then gives particulars of some of the principal brick and stone bridges recently erected. Comparing modern with ancient structures, he points out that the former are built with one-third less material than the latter. In ancient structures the ratio between the thickness of the piers and the span varied from one-fourth to one-half, while in modern it has been reduced to one-sixth, and even one-seventh. The average ratio between the thickness of the arch at the crown and the span was 0·086, while in modern bridges it is from 0·040 to 0·031.

The two principal arched bridges erected in Italy during the last few years are the Ponte Annibale and the Ponte del Diavolo. Each of them has a span of 55 metres (180 feet), and thickness at the crown of 2 metres, the versed sine of the former being 14 metres, of the latter 13·55 metres. Circular openings 9·25 metres in diameter, are introduced to lighten the haunches. These are the largest masonry arches in the world, with the exception of one at Chester of 61 metres span, and one on the Washington Aqueduct in America of 67 metres. In the year 1370, however, an arch of 72·25 metres (237 feet) span, and 20·70 metres rise, was erected over the Adda, at the Castle of Trezzo. This arch was considered the eighth wonder of the world, both for size and for the short space of time—seven years and three months—occupied in its construction. The Ponte Annibale and the Ponte del Diavolo were built in twelve and ten months respectively.

Among recent improvements in detail the Author mentions the use of hydraulic lime and cement, which allows the centres to be struck very shortly after the completion of the arch; and the use

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxiv., p. 354.
[2] *Ibid.*, vol. xxvii., p. 443.

Digitized by Google

of sand-boxes instead of wedges for slacking the centres, a system which he strongly recommends.

The two above-named bridges were built almost entirely of brick, great economy being thereby effected as compared with stone. The Chester bridge, of 61 metres span, cost £83 per square metre of roadway; the Ponte Mosca at Turin, of 45 metres span, cost £105 per square metre of roadway; whereas the Ponte del Diavolo cost only £34, and the Ponte Annibale £24.

The Author concludes by predicting that the limiting span of brick and stone arches has not yet been reached, and anticipates the erection of spans of 100 metres.

W. H. T.

Ventilation and Cooling of Alpine Tunnels.

By Wilhelm Pressel.

(Wochenschrift des österreichischen Ingenieur- und Architekten Vereins, 1881, p. 238.)

The doubts so long entertained regarding the rate of progress of tunnelling have been solved by the construction of the Mont Cenis and St. Gothard tunnels.

But at both these works the difficulties encountered in ventilating and maintaining an equable temperature mark 9 miles (the length of the St. Gothard) as the limit of length at which the construction and working of tunnels can at present be carried out. On the other hand these Alpine railways represent Grand Trunk lines which convey the traffic from the numerous branch lines on one side of them to those on the other; the regularity and certainty of the traffic is therefore a matter of the highest importance. From experience gained in the working of the few existing Alpine lines, it appears very desirable to reduce the length of the approaches and consequently increase the length of the tunnels, with a due regard of course to direct and indirect advantages to be gained. This is determined by the following considerations:—

1. A comparison of the saving to be effected in the cost of construction and working of the shorter approaches with that of a greater length of tunnel.

2. Whether the construction of a tunnel more than 9 miles in length is feasible?

A few years ago the Author had occasion to study the question, and the following were the conclusions arrived at:—

The direction and intensity of the currents of air in a tunnel are dependent on the following:

l = length of the tunnel.
h = difference of level at both entrances.
q = area of cross-section of tunnel.
u = perimeter (internal).

Digitized by Google

s = mean internal temperature.
t, t' = temperature of atmosphere at mouth.
d, d' = atmospheric pressure at mouth.
f, f' = hygrometric condition of same.
w, w' = force and direction of the wind.

From h, in conjunction with t, t', d, d', and w, w', there results either an increased, diminished, or under unfavourable circumstance, suspended draught. At these elevations the average temperature in long tunnels piercing lofty ranges is almost always, even in summer, higher than t, t', consequently the hot air in the tunnel rises to the more elevated entrance and there escapes, and is replaced by that streaming in at the lower mouth of the tunnel. At any rate such is the case during the night, when the temperature in the Alps always falls. A continuous current of air through the tunnel can therefore be reckoned on with certainty for several hours consecutively, its force being dependent on the magnitude of h. But as h increases, so does the gradient in the tunnel, which augments the quantity of smoke given off. The latter is a product it is imperative should be reduced to a minimum, and to do this a gradient of 5 per 1,000 must not be exceeded, *i.e.* the advantages due to a difference in the levels at each end must be sacrificed. At Mont Cenis, with a steep gradient on the western portion (difference of level = 140 metres), productive of a strong draught, if the ever-varying condition of t, t', d, d', f, f' and w, w' combine to produce an unfavourable result, the draught becomes so imperceptible as to be almost a calm; but, worst of all, the smoke accumulates and is kept floating backwards and forwards in the upper part of the tunnel. On the other hand, were the difference of level reduced, which would in other respects be most advantageous, this to and fro movement of the smoke would be aggravated. A moderate draught is therefore evidently insufficient to clear a tunnel of its smoke. Shafts, again, are not of much use, for they are often productive of counter-currents, and in hot sunshiny weather do not act at all; further, they need to be sunk at depths so great that the cost alone forbids their adoption. Neither a small nor a great difference in level will ever produce a permanent, natural, free current of air sufficient to clear these long Alpine tunnels of smoke, either with or without the aid of shafts. To secure this more effective measures must be adopted. The means provided for ventilating the Mont Cenis tunnel are universally acknowledged to be insufficient. The inefficiency of the compressors and the friction in the supply pipes reduce the pressure to such an extent as to be all but inappreciable. In spite of the ponderous machinery employed, and the excellent arrangement of the blowers, the compressed air is delivered at a rate scarcely sufficient to keep even the refuges for the permanent-way gangs free from smoke. The apparatus for exhausting the foul air, which was subsequently erected, is also ineffective. So that a system of this description, however elaborate, does not satisfactorily ventilate

Digitized by Google

the vast space inside a long tunnel. To cause a draught, *i.e.* a continual adjustment of the equilibrium of the atmosphere, it is necessary to reproduce the same conditions which serve to produce those mighty currents of air called wind. The greater the condensation or rarefaction the more violent will the current of air be. To effect this a permanent difference in density must be maintained at the opposite extremes of the column of air passing through the tunnel, which difference must to some considerable degree exceed that of the terms t, t', d, d', and f, f' (neglecting w, w' for the present).

The admission of fresh air and the exhaustion of that loaded with the heat and smoke produced by the passage of the trains, must not be by means of the tunnel mouths, but, these being closed, (sealing is unnecessary) the fresh air must be admitted down one shaft, and the foul air exhausted by another at the opposite extremity of the tunnel, the condensation or rarefaction being provided for in one or other of these two shafts.

The experience gained at Mont Cenis proves that the best machinery is incapable of producing the desired result; some other simple but natural means of producing a difference of tension in the condition of the atmosphere at the opposite ends of the tunnel must be sought for; and first, it must be determined whether the temperature of the air at one or other extremity is to be raised or lowered (a combination of both operations being left out of the question). The old system of ventilating subterranean workings by means of a furnace in one shaft to heat and rarefy the air so that it rises and escapes, the vacuum thus caused being supplied by fresh air admitted down another shaft, fulfils its object to perfection. But at the same time it must be borne in mind—(*a*) that the expenditure on account of firing material would attain colossal dimensions if the ventilation is, under all circumstances, to be thoroughly maintained. (*b*) In these long Alpine tunnels it is not only the accumulation of smoke, but also the heat radiating from the sides of the tunnel which has to be dealt with. Any artificial system of ventilation must therefore provide for both; that is, exhaust the smoke and cool the tunnel. The fresh air must not only be admitted in a sufficient quantity but also at the lowest possible temperature. Fortunately nature solves the difficulty by furnishing an abundant supply of water at a temperature exactly suited to the purpose. To utilize this a vertical shaft, 200 or 300 metres in depth, should be sunk into the tunnel, some short distance from the entrance; down it a continuous fall of glacier water is conducted at the rate of 100 or 150 litres per second; this cools and condenses the column of air in the shaft, carries it down into the tunnel, displacing the warm rarefied air, which rises and escapes up the shaft at the other end of the tunnel. In this manner a continuous free current of air is maintained, its force and intensity being dependent on the depth of the shaft and the volume of water descending it. A difference of 10° in the temperature of the air admitted and that

Digitized by Google

in the tunnel is sufficient to ventilate the tunnel even under the most unfavourable conditions of the temperature, pressure and moisture of the external air, as well as of the direction of the wind. By means of semicircular revolving iron screens 8 to 10 metres in height the disturbing influence of the wind can be prevented and made even to increase the effective draught down the shaft and through the tunnel.

According to the variations in *t t'*, *d d'*, and *f f'* the artificial ventilation is controlled by the partial or total closing of the draught doors at the entrances, and by the volume of water admitted into the shaft; to regulate this special telegraphic communication must be provided. When the temperature is low, at any rate during frosty weather, the water may be turned off, the shaft closed, and air admitted through the tunnel. There is no danger of the temperature of the walls of the tunnel ever being reduced in any perceptible degree by the continuous current of cold air, for these mountain ranges contain a practically inexhaustible supply of sensible heat. As the length of a tunnel increases so should its internal dimensions; *e.g.*, with a length of 18 to 24 kilometres the height should be from 8 to 9 metres. In lengthy tunnels it might also be of advantage, and perfectly practicable, to cool the lower stratum of air by means of jets of cold water arranged at certain distances. The method of ventilating long tunnels already completed and open for traffic, as above described, could also, of course, be employed during construction.

In conclusion, it is submitted that the problem proposed has thus been practically solved by the suggested employment of means furnished by nature, and without the intervention of any mechanical appliances.

W. A. B.

Methods of Improving Rivers having a considerable Fall, and with Beds liable to Scour.

(Les Annales des Travaux Publics, November 1881, p. 498, 1 pl., 12 woodcuts.)

Rivers with a considerable fall, and flowing in a channel scooped out of a very thick bed of gravel, resemble torrents. When the water is high, the fall is fairly regular; but when the water is very low, a series of rapids occur at the shoals, separated by nearly level reaches in which the channel is deep. The removal of one or more of the shoals by dredging only leads to an increase of fall at the rapid above, and is therefore not a satisfactory remedy. Another method of regulating the fall in such rivers is to restrict the channel within low parallel embankments. Such a plan, however, whilst concentrating, and therefore deepening the stream, increases its velocity, and a scouring of the bed consequently takes place till a fresh series of shoals and pools are formed, restoring the

Digitized by Google

river to its original condition. Two methods of improvement have been proposed for this class of river, namely, (1) the restriction of the channel by low training banks; and (2) the erection of movable weirs, accompanied by a partial contraction of the channel. The first method has been carried out on the Rhone for the last twenty years, and the last still remains to be tried.

1. *Improvement by low training banks.*—The method adopted in the first instance on the Rhone consisted in restricting the channel at shallow places by lengths of longitudinal embankments, giving it such a width that, with the maximum discharge and the mean fall, the depth should be 5¼ feet. It is not surprising that this plan did not effect the desired result on such an irregular river as the Rhone, whose depth varies from 2 feet to 26¼ feet, whose width is from 430 to 1,640 feet, whose fall is sometimes only 2½ inches per mile, and sometimes reaches 31 feet per mile, and whose bed is much scoured by floods. The next plan tried was training the river by embankments, following the natural windings of the river, and placed 590 feet apart. Then, as the river tended to form deep channels close to the concave banks, and left shoals on crossing from one concave bank to the next, the banks were brought closer together at these points of inflexion, so as to increase the scour at these points. Though, however, the shallow places were thus improved, the water-level was lowered above, and gravel accumulated below. The defects of the channel are, accordingly, not removed, but their positions are shifted.

In order to regain, in the deep portions of the river, the fall lost by the contraction of the shallow channels, it is proposed to erect compensating dykes, cutting off the deep parts of the channels at the concave banks, and thus to force the river to scour out the shallower parts and obtain a fall sufficient to compensate for the lowering of level produced at other places. This plan would doubtless answer if the bed was sufficiently stable. It is probable, however, that, with a bed so liable to scour, the new channel would become as deep as the old one, and the increased fall would be lost. A system of continuous embankments would set the whole river bed in motion, and the masses of gravel brought down might break the banks and form shoals. Low embankments, moreover, are dangerous for navigation, as they create currents, and vessels may be injured by grounding on them.

2. *Improvement by means of movable weirs, and partial contractions of the channel.*—The contraction of the channel by embankments improves that portion of the channel, but lowers the water-level. This lowering may be prevented by the erection of a movable weir, lower down the river, which keeps up the level and thus maintains the depth of the channel above. An illustration is given of the movable weir which M. Pasqueau has proposed putting up, across the Rhone, at Grigny. It has been designed in accordance with the principles laid down by M. Tavernier, namely, that in rivers bringing down large quantities of gravel, like the Rhone, the weir should be worked from a high fixed bridge above flood

Digitized by Google

level, and that the movable parts should be capable of being raised out of the river. The movable weir, when opened, would not impede the flood discharge; and a portion of the river would have a sill 3¼ feet below low-water level, so as to afford an outlet for the gravel travelling down the river.

L. V. H.

The River Olona Conservancy. By L. Mazzocchi.

(Il Politecnico, Jan. 1881, p. 390.)

After a brief historical sketch of the government of the river during the last three hundred years, the Author describes its course, which, commencing in the Alps at an elevation of 1,800 feet above sea-level, takes a south-easterly direction for a length of about 44 miles, till it reaches the Darsena, under the walls of Milan. It receives two principal and numerous smaller tributary streams, and nineteen torrents. Formerly the Olona discharged into the Po at S. Zenone, after a course of 74 miles; but the Milanese diverted it above Rho, through an artificial channel, into the bed of the Nirone, near Milan, and afterwards into the Darsena. The mean width of the stream is 16½ feet from its source to Malnati; 46 feet thence to Nerviano, and 26 feet thence to Milan. The average fall is 6 per 1,000, the greatest (between Rasa and Malnati) 22·6, and the least (between Rho and Milan) 2·5 per 1,000, the total fall being 1,427 feet. It touches forty-five communes, and is crossed by fifty-seven bridges.

The stream is used by five hundred and forty-four persons, who contribute towards its maintenance in proportion to the area of land irrigated and the number of water-wheels owned by each. The stream was surveyed in 1608, again in 1801, and again in 1877. There is a map of the stream on a scale of $\frac{1}{2.000}$th. The area irrigated increased between the years 1608 and 1877 from 1,747 to 3,022 acres. The number of "rodigini"[1] was 448 in the former year, 427 in the latter. The flow in the stream above Malnati is from 3½ to 12 cubic feet; this is increased by the tributaries to 99 cubic feet at Castellanza, and thence diminished by the abstraction of water for irrigation, till at Milan it is only 10½ cubic feet. In summer the lower part of the bed is frequently nearly dry.

The period of irrigation, as fixed by law, is from the middle of March to the middle of September. The days of the week on which water may be extracted are also fixed by law, the river being divided into three lengths for this purpose, and certain days allotted to each length. There are, however, certain pro-

[1] The "rodigine d'acqua," is a measure equal to about 7 cubic feet per second. This, with a fall of 5 feet, is sufficient to drive a single corn mill by means of an ordinary water-wheel.

Digitized by Google

prietors who have the right to take water throughout the summer, and others throughout the year. The size of the sluices of which there are two hundred and eighty (besides those used for industrial purposes) is also fixed.

The amount of water for each mill-wheel is also strictly regulated; the total power obtained from the stream is equal to 3,200 HP., used for driving thirteen cotton-spinning, five spinning and weaving, ninety oil- and twenty other mills—the valley of the Olona, being now a most thriving centre of industry, owing to the care with which the water is used and regulated.

Various plans have been proposed for providing a larger supply of water, which is greatly needed; among others that of sinking tube wells. Two hundred and forty-one of these tubes were sunk last winter, and it was anticipated, from trials on a small scale, that these would furnish 10½ cubic feet of water per second, at a cost of £1,200. The average depth sunk was 15 feet; one hundred and eighty-four tubes were 2¾ inches in diameter, the remainder 3½ inches.

W. H. T.

The Flow of the Sudbury River, Massachusetts, for the years 1875–79. By ALPHONSE FTELEY.

(Transactions American Society of Civil Engineers, vol. x., 1881, pp. 225–250.)

The Paper contains the results of daily gaugings of the Sudbury river for several years. The watershed comprises 78 square miles, of which one-sixth to one-eighth is covered with wood, the rest being agricultural. Part of the flow of the river is diverted into Farm Pond for the supply of Boston, the remainder passing over a low timber dam. The whole flow consists of the discharge for the supply of the city, passing down a regular channel; the change of volume in Farm Pond 200 acres in area; and the waste over the timber weir. These three quantities were ascertained separately. The flow in the regular channel with different levels of water was ascertained by experiments with floating rods, and the daily computations of the flow from the water-level were checked by observations with a current meter. The variation of volume in Farm Pond was ascertained from daily observations of its level. At the timber dam the water flows when the river is lowest through a timber flume—and is measured at notches placed in the flume—or from tables of the flow with different depths based on experiments. The results were checked by frequent use of the current meter. When the flow is larger it passes over the dam, which has a well defined level crest. The flow was calculated from tables based on experiments with a similar weir. All the observations necessary for determining the flow at the dam were reduced to the registering of the water level. This was at first taken three times a day. Afterwards a registering gauge was used. In freshets the flow was measured at a regular portion of

Digitized by Google

the stream bed, having a plank floor, by means of a current meter. The following Tables give the most interesting results obtained.

Years.	Total Discharge of River in Million Gallons.	Average Daily Discharge in Gallons.	Average Discharge in Cubic Feet per Second per Square Mile of Drainage Area.	Total Rainfall Inches.	Rainfall Collected. Inches.
1875	27,594	75,599,200	1·500	45·49	20·42
1876	32,310	88,278,400	1·760	49·56	23·91
1877	34,445	94,369,200	1·880	44·02	25·49
1878	41,202	112,882,200	2·250	57·93	30·49
1879	25,529	69,942,200	1·380	41·42	18·78
1880	16,562	45,250,300	0·920	38·18	12·49
Mean	29,607	81,040,500	1·615	46·10	21·93

Years.	Rainfall Collected. Percentage.	Flow for July, August, September, and October. Average Daily Discharge in Gallons.	Cubic Feet per Second per Square Mile of Drainage Area.	Percentage of Rainfall Collected.
1875	44·88	30,650,400	0·60	16·05
1876	48·24	19,603,300	0·39	10·08
1877	57·90	19,832,100	0·39	11·67
1878	52·63	25,001,600	0·50	12·92
1879	45·33	14,974,000	0·30	10·32
1880	32·71	9,356,100	0·19	5·55
Mean	47·56	19,902,900	0·40	11·22

Years.	Maximum Flow on any Day. In Cubic Feet per Second per Square Mile of Drainage Area.	Minimum Flow in any Month. In Cubic Feet per Second per Square Mile of Drainage Area.	Minimum Flow in any Week. In Cubic Feet per Second per Square Mile of Drainage Area.
1875	19·30	0·16	..
1876	41·39	0·28	0·080
1877	22·08	0·09	0·036
1878	15·61	0·20	0·105
1879	21·36	0·11	..
1880	..	0·13	..
Means	23·95	0·16	0·074

The greatest flow per second (taken from the daily observations) was 1,150 times the least flow per second taken from the observations for a week. Some additional data of the minimum flow and flood discharge of other American rivers are also given.

W. C. U.

Digitized by Google

Blasting under Water. By J. Deutsch.

(Wochenschrift des Oesterreichischen Ingenieur-und Architekten Vereine, 1881, p. 245.)

The Author, as delegate of the Austrian Engineers and Architects Association, attended the experiments conducted by Major Lauer before a commission, appointed by the Imperial Minister for War, to report upon his method of blasting under water by means of a charge laid upon the surface of the mass to be operated on, and fired by electricity.

For carrying out this operation an ordinary river-flat or barge is employed; over the stern two beams are rigged out, in which a couple of uprights, connected at the top by a cross beam, are fixed; in the centre of this cross beam there is an iron stirrup; the uprights are further strengthened and stayed by a couple of longitudinal ties.

A movable grating forms the floor of this overhanging stage at its extremity, and across its entire width there is a row of apertures through which the sounding-rod works, after passing through the stirrup on the cross beam, and which together regulate the position and direction it is desired the rod shall assume.

The rod itself is made up of several lengths of 1½-inch gas-pipe, each length being fitted at one end with a solid iron mandril, at the other with a strong coupling. A chain attached to its lower extremity enables it to be lowered or raised by hand from the deck of the flat. This arrangement permits of the rod being adjusted in almost any position, and so as to reach any point within a circle of considerable area at the bottom of the water. The soundings, however, are all taken at an angle which by a simple calculation gives the true vertical depth, all necessary data being known. The depth may vary without being perceived and alter the angle, which might have the effect of changing the position of the blast; on this point the jury expressed preference for a system of vertical rather than of angular soundings. For the purpose of these experiments a mass of gneiss traversed by veins of quartz was selected, situated in the bed of the Danube near Kreus, and at a depth varying from 9 to 11 feet, the surface velocity being 10½ feet. The experiment occupied nine consecutive days, or six hundred and six working hours, and gave an average performance per day of ten hours of three hundred and fifty soundings and seventy-two blasts, each sounding occupying twenty-five seconds, and each shot from four to five minutes; the rest of the time was spent in altering the position of the barge. The total number of shots fired was three hundred and ninety-nine, on which 294 lbs. of dynamite were expended, and 43 cubic yards of rock removed. The force of the current washed away the *débris*, and the mass thus removed was ascertained by soundings taken shortly after each explosion; had this been practicable later it is probable greater results would have been recorded. The cost

Digitized by Google

per cubic metre was found to be 12 gulden, 6 per cent. less than it has been estimated similar work at the Iron Gates, performed in the ordinary way, has cost.

A comparison of the system commonly adopted and that recommended by Major Lauer shows that the distinctive features of the latter do not so much lie in the fact that the charge is simply laid upon the object to be operated upon, without drilling or loading a hole, but rather in the ease and rapidity with which the charge is laid, and the precision with which the operations of sounding and blasting can be conducted. Besides, it must be remembered that the very obstacles which render the present system tedious and expensive, viz., great depth of water and strong currents, actually contribute to the economic success of the Lauer system, which puts blasting under water almost on the same footing as blasting on land.

The cost of blasting operations generally, whether above or below water, depends on the structure of the rock rather than its hardness; and the local peculiarities in each case, whatever they may be on land, are certainly much exaggerated when encountered under water, where the sense of sight is inoperative, and that of feeling, mechanically supplemented by the sounding rod, alone available. Under the present system, especially where the water is deep and the stream rapid, the operation of drilling the hole is attended with uncertainty and great difficulty, and, if during the process the water vary considerably in depth, a satisfactory completion of the hole is almost impossible. This, together with the expense of the staging required, and the time occupied in removing and replacing it before and after each explosion, and preventing the bore-hole silting up, contribute to make the present system, even under the most favourable circumstances, a most expensive one; so that, even before the invention of dynamite, the plan of depositing free charges of gunpowder on the surface was resorted to in the years 1858–60 for blasting operations in the harbour of New York, with favourable results.

With dynamite the same system was further employed on the coast of Dalmatia, but with unsatisfactory results, due probably to local peculiarities.

W. A. B.

Hydraulic Canal-Lift at Fontinettes, near St. Omer.

(Revue Industrielle, Paris, 1881, p. 394.)

This lift, the first about to be established in France on the system of Messrs. Clark, Standfield, and Clark, connects two reaches of the Neufossé canal having a difference of level of 43 feet, and is to replace an existing set of five rise locks. The general disposition of the work follows the prototype at Anderton,[1] but some

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 107.

Digitized by Google

modifications have been introduced, by which a considerable saving of water is effected. The two troughs are 147 feet long, 16 feet 4 inches wide, and 6 feet 6 inches deep, and communicate at the upper level with an aqueduct of wrought iron, 165·5 feet long, supported at two intermediate places on iron columns, and continuing the upper part of the canal, over a double line of railway, to the site of the lift. As at Anderton, a single central ram supports each trough, but in this case the ram is 6 feet 6 inches in diameter, and has a stroke of 43 feet (13·13 metres). The extremity of the aqueduct rests upon a substantial double-arched pier of brick and masonry, flanked by two towers of ornamental design, one of which contains an accumulator. On the top of this pier is situated the cabin of the man who directs the manœuvring of the lift. Each bay of the pier carries guides for one end of one trough; the other ends of the troughs work in guides in a similar double-arched pier. This outer pier is flanked by two smaller towers, which contain compensating reservoirs in the shape of two iron cylinders of the same height and diameter as the rams. Articulated pipes, attached at their bottom ends to the lower parts of these reservoirs and at their upper ends to the rising and falling troughs, keep up at all times the connection between each of the reservoirs and its corresponding trough, and thus the water takes the same level in the reservoir as in the trough. If now one trough be at the upper level, and there is added to it weight sufficient only to overcome friction and inertia (the reservoir being full), water will pass during the descent from the reservoir to the trough, and, inversely, from the descending ram to the ascending one. These two actions compensate each other by reason of the equal diameters of the reservoirs and presses. The equilibrium between the two troughs is therefore maintained without, and the only loss of water is that necessary to overcome the passive resistances. In the Anderton presses the friction was taken as $\frac{1}{40}$ of the total weight to be lifted. If the same coefficient be adopted for the Fontinettes lift, where the total weight to be raised is 800 tons, this value will be 20 tons, corresponding to the weight of a 3 to 4-inch layer of water in the trough. Further, the lower trough, holding in this position all the water from its compensator, will have a greater depth of water by 6 inches than the canal.

To obviate as much as possible the loss of water accompanying the manœuvring of the lift, the lower as well as the upper section of the canal has been furnished with gates, and a dry chamber has been constructed as a continuation of the lower part of the canal, in which the trough lodges when at the bottom of its stroke. By this means there is no occasion (as at Anderton, where the trough plunges into the lower water) to inject water under pressure in order to make the final movement of the ascending lock. At Fontinettes a small accumulator suffices to charge the presses for the first time, to make good any escapes, to compensate the effect of any sudden rises in the canal, and,

Digitized by Google

above all, to facilitate the adjustment of the water-level in the troughs. The accumulator press has a diameter of 17·7 inches, and a stroke of 26 feet 3 inches; the pressure reaches 30 atmospheres. Three men suffice to work the lift, and a single operation only causes the loss of 20 cubic metres (about 20 tons) of water.

F. G. D.

Contrivance for Working the Needles at the New Overfall at Port-à-l'Anglais Weir. By M. Lavollée.

(Annales des Ponts et Chaussées, Sept. 1881, p. 220, 1 pl.)

The object of the contrivance, devised by M. Guillemain, is to facilitate the working of long heavy needles where there is a great depth of water, or where the fall is considerable. The contrivance consists of a hook attached to each needle, near its upper end, and encircling the top front bar, connecting the frames, against which the needles rest. The bar is made round, and the hook enables the needles to revolve about it, in a plane parallel to the current, and either up or down stream.

In lowering a needle, the weir-keeper, having laid it across the foot-bridge, pushes it in an up-stream direction till the hook catches the bar; he then lifts the upper part of the needle up by its handle, so as to dip its lower end into the stream, which acting on it forces it against the sill. The shock of the needle against the sill is reduced by adjusting the position of the hook so that the bottom of the needle in descending may bear slightly upon the apron before reaching the sill.

In lifting a needle, it is only necessary to raise it by a crab, or other mechanical contrivance, till it is free from the sill, when the current causes it to revolve round the bar, and it floats on the stream, being retained by the hook. This renders it possible to open the weir on the arrival of a sudden flood, and to defer the removal of the needles to a more convenient opportunity.

The needles at Port-à-l'Anglais are 11 feet 6 inches long and 3 inches square in section. The fall at the weir is 7 feet 10½ inches. A little carriage, running on rails along the foot-bridge, carries a rack and pinion arrangement for lifting the needles, and by its aid the weir-keeper can release forty needles in five minutes. The floating needles are raised, when necessary, on to the foot-bridge by means of a wooden lever pivoting on an upright fixed to the carriage. One end of the lever is attached to the needle to be raised by means of a chain, and the other end of the lever is then pulled down by another chain fastened to that extremity, thus raising the needle.

To test the contrivance, oak needles, 13 feet 1½ inch long, 8 inches wide, and 4½ inches thick, were experimented upon. One man was able to put these needles in place, although it took two men to carry them on to the foot-bridge.

Digitized by Google

The addition of hooks to the needles of a movable frame weir costs about 4*s.* 10½*d.* per lineal foot of weir; the rails for the tramroad on the foot-bridge cost about half that amount; whilst the cost of the carriage complete amounted to £12.

L. V. H.

Rolling Foot-Bridge over the Duquesne Lock at Dieppe.

By N. ALEXANDRE.

(Annales des Ponts et Chaussées, Oct., 1881, p. 327, 2 pl.)

The swing-bridge over the Duquesne lock connects Dieppe with its largest suburb, and with several villages inhabited by workmen. Fifteen thousand foot-passengers cross it daily. At high water the communication is interrupted during the passage of vessels through the lock, which is a serious inconvenience to the traffic, especially when high water occurs at the time the workmen are leaving or returning to their work.

The swing-bridge having become defective, a temporary rolling foot-bridge was constructed to supply the place of the swing-bridge whilst it was being rebuilt. It was necessary that this foot-bridge should be easily and rapidly moved, so as to interrupt the traffic as little as possible, and should be strong enough to support a large crowd and to resist the wind.

The foot-bridge has a single span, and rolls backwards and forwards on rails, being supported on two iron axles 4½ inches in diameter, carried by four cast-iron rollers. It is formed of two wooden trellis girders placed 6 feet apart, 5¼ feet high, 102½ feet long, and braced together under the planking of the footway. The bridge has a spanning portion 60 feet long, and a tail-end 42½ feet in length; and the footway is divided into two halves by a railing.

The total weight of the bridge, with its machinery, is about 25 tons, including 3½ tons of cast-iron kentledge. These weights are so distributed as to give an excess of 3 tons beyond the absolute balance. This excess was added to secure the tail-end rollers from being thrown off the rails by a shock or by the pressure of the wind. Four men work the bridge, which is rolled into place across the lock in from sixty to seventy-five seconds, whenever there is a spare interval of four or five minutes between the passage of vessels.

The bridge, which was erected in 1879 at a cost of £400, has worked perfectly even during gales.

L. V. H.

Digitized by Google

On the Formation of Sandbanks and Sandhills, and the Construction of Harbours on Sandy Coasts. By H. KELLER.

(Zeitschrift für Bauwesen, 1881, p. 175.)

The Author holds that all coast lines are in a continual state of change from the action of the sea, the rate of variation being slower as the materials of the land are more resisting, and the force of the waves less great. The general effect is to wear down promontories and fill up bays; but to this there are many exceptions: thus the point of Dungeness has advanced 90 yards in fifty-two years. Such cases are due to the action of special currents, combined with low wave power.

Sandy Coasts.—The rock and earth of the cliffs, after being shaken down by the breakers, are by the same cause ground into smaller and smaller fragments, till they arrive at the state of sand. The fragments are roughly sorted, according to weight, by the carrying power of the waves, and when they have reached a depth too great for direct wave action, the finer portions are still moved by the currents. By studying the geological character of the shingle and sand at various points of a coast, the direction of its drift, and consequently that of the prevailing currents, can generally be determined.

Flat coasts, especially of the tertiary and quaternary formations, are the chief localities of sand, owing both to the large area which is acted on between high and low water, and to the large horizontal motion of waves in shallow water. At the water's edge, where the waves are finally spent, a flat and even strand is formed: further down, where the advancing and retiring waves meet in conflict, the sand is violently agitated, and heaped up into ridges, while during each movement it is carried onwards for a short distance by the set of the prevailing current. These currents, and the sand they transport, pass straight across the mouths of narrow inlets or bays, and thus form bars or sandbanks, which often convert the latter into lagoons. Similarly a row of islets may be connected with each other, and with the mainland, by accumulations derived from such currents. The quantity of sand thus transported, on any given sandy coast, cannot easily be estimated. Where harbours are choked by it, dredging operations, though useful in the case of shingle, are of no permanent avail, in consequence of the inexhaustible supply of sand furnished by a long coast-line; and no operations for cutting off this supply are of much effect.

Influence of River Silt.—The mud and sand brought down by rivers add of course to the accumulation of sandbanks, though much of it is so fine as to be carried at once into deep water. The amount of this addition does not depend so much on the quantity brought down as on the coarseness of its quality, and the effects of winds and currents at the river mouth in causing it to settle near

Digitized by Google

or far from shore. The shingle is of course deposited first, then the sand, and lastly the mud.

Breadth of Quicksands.—Various observations seem to show that the zone of quicksand, *i.e.*, of sand continually in motion, does not extend below the point at which the direct or indirect action of the waves ceases; its breadth is therefore in general small.

Formation of Sandbanks.—Wherever a current charged with silt has its speed seriously reduced, deposition may take place. The cause of such reduction may be the meeting with an obstacle, such as an island or wreck, the meeting with another current, a change of direction, &c. Of these the second is the most important; the same cause which makes the sandbanks prevents their rising into islands, and they often become very large. The two currents may be both ocean currents, due to temperature, or one an ocean current and the other the outflow from a river.

Effect of Storms.—Were the weather always equable, the changes of a coast-line would be very slow, depending only on the erosion of land by the sea and by the rivers, and on the shifting of the sand by currents; storms, and "storm-floods," by which is meant the heaping up of the sea against the coast in heavy landward gales, have, however, a very great and disastrous effect in breaking up sandy shores and sweeping away the materials. The rounded outline of the east coast of England, as compared with the deeply-indented coast-line of Friesland, is evidence in itself that in the German Ocean the prevailing gales are from the west. Such washing away of the coast may be assisted by geological causes, such as the yielding nature of the strata, or a secular sinking of the land. The result is the retreat of the land in most places, often accompanied by an advance elsewhere, where the materials washed away are deposited. In many places the latter has been largely assisted by human enterprise in the way of reclamation.

Coast Currents.—The main causes of ocean currents are differences of temperature; but these differences are greatly lessened in the neighbourhood of land. Apart from special local currents, such as those flowing out of inland seas, the main cause of powerful coast currents, such as move sand and shingle, is the wind. Such currents usually change their direction as the wind shifts, and the general drift of the sand is in the direction of the prevailing winds. The energy of waves driven by such winds against the shore in an oblique direction is expended partly in heat and erosion, but mainly in moving the water, sand, &c., partly up and partly along the beach. The latter movement is the greater, as the wind is more oblique to the coast-line. Coast currents thus formed have in some cases a speed of 6 feet per second, and extend to a depth of 30 feet, and it is these irregular currents which mainly cause the movements of sand and the formation of sand-banks.

In regions where the range of tide is considerable, the currents of ebb and flow add another important factor to the causes of sand movement. They sometimes assist and sometimes oppose

Digitized by Google

the effects of wind-currents and temperature-currents, and have the greatest influence on shelving coasts, where that of the waves is less than on flat coasts. The periods of maximum velocity, both of ebb and flow, the duration of each, &c., are very much influenced by the peculiarities of different seas and estuaries, and must be studied separately for each case.

Formation of Sandhills.—When the wind blows nearly perpendicularly on a sandy coast it stirs up the dry sand, and drives it onwards in successive bounds. Where the sand is stopped by natural or artificial obstacles sandhills accumulate, which may be formed into regular chains of "dunes." If an oblique wind from the sea blows upon such dunes, it disturbs their seaward face (unless it be properly planted or fascined), and drives the sand partly inland over the top, partly along the face. In this manner thick clouds of sand often travel along the coast, and sometimes choke up the mouths of streams, &c. Where there are openings in the foremost dunes, the sand rushes through, and forms other dunes further inland. The sand of such dunes is thus continually travelling, both along the coast and inland—an evil which can only be checked by planting the dunes with vegetation, and by continual care. In some cases complicated systems of dunes are built up by local causes, and form sandy wastes of great extent. The opposite effect, viz., the blowing of sand into the sea by seaward winds, is not usually of much importance.

Action of Engineering Works on the Coast-line.—The object of such works is either the warding off of dangerous currents, or the causing sand to accumulate at particular places, or the protection of harbours. The first are only required in places where the coast-line is in an unstable condition, as at the mouths of rivers. The second, such as groynes, are intended to form deposits, as it were, of sand, which may eventually check the drift of sand under the action of coast-currents. They can only be very partial in their operation, unless they are distributed over the whole length of coast under treatment. Piers, projected into the sea to protect harbours against the incursions of sand, are generally acknowledged to be only of temporary advantage; since the sand gradually works its way round them, even when they are carried forward beyond the depth at which coast-currents usually operate. Exceptions to this rule only occur where some of the causes of sand movement happen to be absent.

The direction which such piers should take is not fully established. In reclamation works on rivers, a slight inclination against the current is known to be best; but for harbour piers a perpendicular direction may sometimes be preferable. The object should be to divert the sand moving along the shore into deep water outside the harbour, by curves as easy as possible, and allow it afterwards to return to its general direction. The angle between the pier and the coast always forms a sort of bay, in which the waves tend to pile themselves up, and a reflux is thus produced, which cuts out a deep hollow along the pier. The

Digitized by Google

sand entering the angle is carried outwards by this reflux, until it meets at right angles the main coast current, which has been little influenced by the pier. At this point the speed is checked, and sand deposited, which gradually forms a shoal in the line of prolongation of the pier. This shoal shelters the water between it and the pier, and favours the deposit of sand there; so that eventually a compact sandbank is formed round the head of the pier, and extending some distance in front of it. For these reasons an inclination in the direction of the current seems the best. The heaping up in the angle is then less, and the sand comes out at an angle to the coast current, and mingling with it is carried forward without settling. This will be facilitated if the shape of the pier is made convex towards the current, which at the same time leaves the shore behind it quite open to the sweep of the seas, and assists the transport of the sand into deep water. Whatever form is adopted, such harbours will, however, always require a great deal of dredging inside. The reason is twofold; first, that the set of the flood tide usually diverts the coast current into the mouth of such harbours, and deposits the sand in the still water; secondly, that in storms the waves fling masses of sand-laden water into the harbour, with the same result.

Thus at Boulogne the shoal of La Bassure lies off the mouth of the harbour, and leaves between itself and the coast a narrow and deep channel, to which the shore falls in terraces. The Atlantic tide-wave, coming in from the west, causes strong currents along this channel in alternate directions; and since the new piers, now building, will be carried out into this channel, it is hoped that these currents will keep the entrance always open, although dredging will no doubt be required within the harbour. On the other hand, the harbour of Ymuiden, lately constructed with two piers inclined towards each other, after the model of Kingstown, already shows signs of shoaling near the entrance.

Action of Scouring Currents on the Coast-line.—By a scouring current (*Spülenstrom*) is meant any current (generally that from a river or estuary) which prevents the formation of sandbanks by scouring them away as they are deposited. Where the current is due to a river, its effects will be greatly influenced by the amount of silt it carries of itself, which may even turn it from a scouring to a depositing current. Where it comes from an estuary it is generally clear, because the estuary forms a settling basin, in which the silt is deposited. In some cases the current may be due to the reflux of the waters driven into a lagoon by the wind; but such entrances, unless under very rare circumstances, can never be permanent.

In the two former cases the scouring is continuous, but varies greatly in intensity with the time of year, height of tide, &c. The direct effect of a current of clear water is to drive outwards the coast current and the sand it carries, which is gradually deposited in the form of a concave bar round the mouth of the river. This is usually cut through in one or more places by

Digitized by Google

narrow channels, its form, &c., depending on the relative action of the fresh water, the coast current, and the prevailing wind. The outer side of this bar is acted upon by the waves, and when there is a gale full on then the sands on this side are stirred up, and carried over to the inner face of the bar, or even into the harbour. By this means the bar may sometimes be increased in height, and moved towards the harbour, in spite of the fresh water efflux. This efflux can often be concentrated, and so made more effectual, by the construction of piers.

Currents entering the estuary from the sea bring in silt, which is deposited where the current dies away, *i.e.*, in rivers at the upper limit of the tide, and in lagoons at the inner end of the connecting channels, which thus gradually silt up.

Where the upland waters are not clear, but carry silt and shingle, things are altered. The former mainly passes at once into deep water; the latter settles first on the inner bar just described, until a flood carries the whole of this bar into the sea, where it goes to increase the outer bar. This bar, gradually rising on each side of the river channel, may contract it so much that it may finally be diverted, thus illustrating the formation of deltas.

Action of the Tide in Estuaries.—When the tidal wave is checked by entrance into an inlet or estuary, its forward edge becomes higher and steeper; and where the rise of the bottom is rapid, the depth small, and other circumstances intervene, the regular form of the wave is lost, and it rushes upwards as a "bore." In the case of lagoons, the tide advances more quietly, and generally deposits a good deal of silt; occasionally the ebb leaves the lagoon by a different channel from that by which the flood has entered.

The flood tide, pouring into an estuary, brings with it sand and mud, of which part at least is deposited where the velocity comes to an end. Hence the tidal area of a river is a sort of reservoir of silt, which oscillates up and down till it either sinks permanently to the bottom or is swept out to sea on the ebb. In sheltered places sandbanks and islands are thus formed. The same tends to take place outside the mouth of the river; but then such sandbanks, after having grown to a certain extent, always come under the action of the coast and other currents, and are cut back again. The formation of sandbanks or deltas within the estuary, as described, tends to form the same accumulations outside, because it diminishes the tidal capacity of the estuary, and therefore the power of the ebb to scour these sandbanks away. The final result must be the filling up of the whole of the tidal basin, outside the actual low-water channels, and the conversion of extended estuaries into flat marshes, cut by deep and narrow streams. These will often find their way into the ocean by several mouths, especially where they carry much silt, and are subject to violent floods, causing them frequently to break open new channels. Where, from such causes, an estuary falls below its required width and depth, artificial works become necessary. The object of such

Digitized by Google

works should be to keep the energy and volume of the ebb and flow as great as possible at every part, and at every time. The fall, section, sectional area, and discharge of a stream are all dependent on each other; hence, if the discharge be increased, the fall and section will in general increase also, and, if care is taken that the banks are not attacked, the channel will be deepened. An estuary, however, comprises two different parts—the tidal channel within the river and the basin at the mouth—and these require different treatment. Parallel training banks are the right method in the former, while in the latter the object should be to cut off subsidiary channels, and so concentrate the flow.

Similar considerations apply to the case of lagoons, which must in time either be filled up entirely, or converted into lakes, separated from the sea by banks of shingle and sand.

Harbour Bars.—In the formation of harbour bars, two forces besides the tide are concerned, viz., the prevailing wind and the coast current. Much depends on the angle which the directions of these make with each other. Where wind and tide meet full against each other, the result is a stoppage of velocity and consequent deposition of silt, combined with a violent agitation or surf at the surface. The bar is thus rendered doubly dangerous. The depth of the entrance will in general be greater (as examples show) the more inclined it is to the direction of the waves. Hence the entrances of rivers, in a stormy sea, are seen to take a direction more and more inclined towards the coast, until at last the mouth gets choked by the action of some storm, and the river then breaks a new way straight through the bar. For this reason breakwaters should be made convex to the direction of the wind, so as to give an oblique direction to the current issuing from the harbour.

The Author then treats of the construction of harbours on sandy coasts.

Maintenance of Depth in Harbours.—Most harbours on sandy coasts owe the maintenance of their depth solely to the scouring action of the estuary which forms them. They are usually divided into an inner harbour or dock, and an outer harbour, often connected by a half-tide basin. The outer harbour may be a natural reach of river, as at Newcastle, or an artificial basin. On sandy coasts this basin will in general be in a continual state of silting up, and a bar will be continually forming in front of it, as already shown. All apparent exceptions to this rule are either on large and powerful rivers or on rocky coasts. The interior of the basin can be easily kept clean by dredging, but the dredging of the bar is a different matter.

For cleansing the interior, in cases where the range of tide is great, artificial scour is often resorted to. The water, either tidal or upland, is impounded in a basin, and let out through sluices towards low water. As the issuing stream has first to put the whole water of the basin in motion, it is some

Digitized by Google

time before it reaches its maximum velocity, and this period should be made to coincide with that of dead low water. The silting up of the scouring reservoir itself is often a difficulty, which has not been successfully met by admitting only the upper and clearer layers of the tidal water. If fresh water is used, rubbish, logs of wood, &c., are collected in the scouring basin, and eventually deposited on the bar. The effect of such scour does not reach below a depth of 6 to 9 feet, so that its power upon a bar is limited. It is also inconvenient to the ships using the harbour, and apt to undermine foundations, &c. This may be obviated by placing the sluices outside the half-tide basin, leaving the latter to be cleansed by dredging. The effect of scouring the harbour entrance itself has not been fully tried, but works for this purpose are in course of erection at Calais and Honfleur. In such harbours the piers are generally so long that it is impossible to reach their outer ends by scouring from within (natural or artificial), unless the resistance to the scour is unusually small. To make it act with effect on the bar, the pier should be made concave to the scour, which will run round it and then radiate outwards to the place required. This is preferable to training the current by low-water walls, which impede the entrance and cause surf. Movable training pontoons, moored in the tideway before scouring, have been employed, but should only be used for old harbours, where a permanent pier cannot be had. A much better mode of increasing the scouring effect is to bend the channel as nearly parallel as may be to the direction of the waves and currents, as described above. In general, with the view of assisting the scour, all sharp turns, sudden changes of section, and trumpet-shaped entrances should be avoided, as these tend to weaken the action of the current.

Action of Scour.—Lentz gives 0·75 metre (2½ feet) per second as the lowest velocity that will scour silt, and 1·50 to 2 metres (5 feet to 6½ feet) as the lowest that will scour sand. These are nearly ten times as great as the corresponding values given by Dubuat, &c., for river water; but the explanation is that the former refer to the power of raising and scouring away, the latter to the power of transporting merely. Thus the first of a series of scourings always has the best effect, because it acts upon silt which has only lately settled, and is easy to move. Hence it comes that artificial scour is rarely useful at any great distance from the sluices, because the velocity is lost in causing eddies, and in putting the surrounding masses of water in motion. The remedy is to put the scouring basins right at the mouth of the harbour, as mentioned above. To this the objections are, the expense, and the fear of damage by storms. To avoid this it has been proposed by Bouquet de la Grye to lay pipes, or a masonry culvert, from the scouring basin along the pier, with sluices at intervals, opening upon the entrance. Another suggestion is that of Bergeron,[1] to

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lviii., p. 132.

Digitized by Google

lay pipes along the bottom to the bar itself, and use hydraulic pressure to stir up the sand, which would then be carried away by the ebb tide. The trials of this promising method have not been successful, and the possibility of using it in bad weather is very doubtful. Another method, also suggested by Bergeron, is the use of vacuum dredgers, removing the sand by suction, which work well even in bad weather. These and other mechanical means should only be considered as accessories to the scour, assisting its erosion by forming a channel for it. This has been done at Honfleur by planting a row of piles, or preferably of buoys moored on to the bottom, which, being agitated by the current, form eddies and stir up the sand.

When artificial scour is employed, it generally takes place only at spring tides. The sluices are opened a little before low-water, and the scouring lasts one and a half to two hours. This rarity of action has a bad effect, as compared with continuous natural scour, owing to the opportunity given to the silt to settle and harden. Moreover, the natural scour of the ebb, which at least keeps the silt in suspension, should be taken advantage of. Artificial scour should therefore be more frequent, begin earlier, and continue till the turn of the tide. Difficulties in the way of this can be met by the same means as before suggested, viz., by making the discharge basins and the sluices close to the entrance.

Arrangements of Harbours with regard to Winds and Waves.—In many harbours the easy keeping open of the entrance is of less moment than the protection given from the sea, and the means of safe entrance in all weathers. On rocky coasts and in wide bays the works required for this purpose are generally simple, and consist in removing obstructions such as rocks, and building breakwaters to shelter the whole or a part of the bay from the prevailing winds. Where no bay exists, a harbour can be formed by the building out of two piers, with or without a breakwater in front of the mouth. These piers should not have salient corners, and should be convex, not concave, towards the sea. The harbour should widen rapidly within the entrance, so that the waves may spread out and be lost, and vessels be at once in safety. In designing the entrance, the needs of vessels entering are of course to be considered much more than those of vessels leaving, especially in the case of harbours of refuge. This does not apply so much to harbours on flat sandy coasts, as the depth at low-water is usually too small to enable them to be used as harbours of refuge. Here it is not so much storms which have to be considered as the prevailing wind; and the entrance should be so placed that vessels can make it without sailing at an angle of more than 60° at the outside to this wind. To lay the entrance directly in line with this wind is not advisable. It is quite unnecessary for sailing vessels, especially in these days of steam-tugs; the vessels entering come too rapidly and those leaving are greatly impeded, while the harbour is exposed to the full run of the waves, and the scouring power of the ebb is much reduced. Trumpet-shaped entrances

Digitized by Google

have also this last disadvantage, and increase instead of diminishing the violence of the waves. Whether the two piers should be of unequal length must be decided by local circumstances; in general the best arrangement seems to be that the pier next the prevailing wind should be shorter than the other, as this facilitates the entrance of vessels. The entrance should not be, if possible, perpendicular to the coast current, as it is then harder to make, especially by long vessels.

Artificial harbours have sometimes been made with two entrances, but this is objectionable. In some cases a single breakwater has been built across the mouth of a bay, with an entrance in the middle; but this gives rise to bad cross seas between the impinging and reflected waves. The outer ends of the piers should be inclined inwards towards each other at an angle of about 90°, but not so as to be in a straight line. The entrance should never be exactly opposite the quarter of the heaviest gales. This especially applies if the outer harbour is to be used for unloading goods. When the entrance is long and narrow, it is generally curved gradually away from the direction of the storms. The curve must be very gentle if it is to accommodate the long ocean steamers of the present day.

It is often impossible to attain to all the above advantages, especially in channel harbours, as opposed to artificial basins. In the former the waves are sometimes broken up to some extent by interposing jetties of open pile work, with side basins behind them. It has been found advantageous to make the piers themselves open above low water. On the Tyne and elsewhere the mouth of the estuary has been partly closed by piers, thus forming a sort of basin behind them. This, from its preventing the free ingress of the tide, will probably lead to silting up near to the mouth, though in the case of the Tyne the immense dredging operations higher up tend to remove this difficulty.

After recapitulating the conclusions arrived at, the Paper gives a general project for a tidal harbour on a sandy coast. The points of first importance are protection against waves, convenience of scouring, and prevention of excessive accumulations of the sand travelling along the coast in the direction of the prevailing winds. The pier exposed to this sand must be long and convex, thus enclosing a sort of basin within it. This should be turned into a scouring basin by means of an inner pier run out from the shore with a slight curve to meet the other or windward pier close to the entrance. At the point of meeting the sluices will be placed. Between this third pier and the leeward pier will be the entrance to the inner harbour, which will thus have a channel form. The third pier may be pierced by a number of openings, closed on the ebb but open on the flood, which will tend to dissipate the waves as they enter the harbour, during the time of high water, when the traffic is heaviest. The entrance will be inclined as much as possible to the prevailing wind, and the scouring operations will take place on every tide, and be continued as long as possible, so as

Digitized by Google

to hinder the silt from settling, or stir it up before it has become compact. By such means the bar continually formed by the advance of the sand will be as continually swept away into deeper water. While the construction of these works will no doubt be costly, the depth will thus be permanently preserved at the least possible cost.

The Paper contains sixteen plans of harbours, &c., and a great number of references to particular cases, which for the sake of brevity have been omitted.

W. R. B.

Sluicing Basin at Honfleur. By R. Andra.

(Le Génie Civil, vol. i., pp. 554 and 579, 2 pl. and 6 woodcuts.)

The entrance channel to the port of Honfleur was constantly liable to be silted up, owing to the frequent changes occurring in the main channel of the river which sometimes approaches Honfleur, and at other times passes over towards Havre on the opposite shore. To remedy this state of things, it was decided, in 1873, to secure the maintenance of the entrance channel to Honfleur by constructing a sluicing basin which should retain a large volume of water for scouring the channel at low water. This sluicing basin was completed in April 1881.

The sluicing basin, having an area of 143 acres, has been formed by enclosing a portion of the foreshore in front of the town by means of embankments. An attempt was made, in the first instance, to form the embankments with material dredged from the surface of the basin, which was only from 3¼ to 5 feet below ordinary high water, and which was to be lowered 3¼ feet. As, however, these banks were found not to be sufficiently solid, and the deepening of the basin would have increased the difficulty of closing the banks, material was procured from clayey and partially reclaimed lands to the south-east of Honfleur for forming the central portion of the embankments. The works were commenced towards the end of 1874, and by the spring of 1876 a length of only 1,640 feet remained to be closed between the ends of the embankments. A bank, composed of earthwork mixed with stone, was carried as rapidly as possible across this opening; but the rush in and out of the tide rendered it a difficult task. However, in July 1876, the tide was excluded, and the narrow connecting bank was consolidated with all speed.

The embankment, which was enlarged by material dredged from the basin, is 40 feet wide at the top, and has a slope of 3 to 2 on the inside and 3 to 1 on the seaward side. The inner slope was coated with a layer of stones 20 inches thick, on which a course of rubble stone of the same thickness and set in Portland cement was placed. A trench of compact earthwork was formed along the

Digitized by Google

bottom of the inner slope, and carried down 3¼ feet below it, to protect the bank against infiltrations through the silty foundation. The outer slope was pitched with large blocks of rubble stone; and the foot of the slope was protected, against the possible incursions of the shifting river channel, by 137,000 cubic yards of rubble stone extending down to a more solid stratum situated at a depth of 42 feet below the surface. The river channel, indeed, moved towards the embankment whilst the works of protection were incomplete, and the embankment was only saved from destruction by forming cross jetties with the pitching already laid on the slope and all other available materials.

The cost of the embankment, of which the original contract sum was £68,200, was raised to over £100,000 by the necessary additional works.

Two special works belonging to this undertaking are described in detail by the Author in his second article—namely, the sluices at the outlet of the basin, and the weir at the inlet for regulating the supply of water from the sea.

The sluice has four openings, each 16½ feet wide, separated by piers 6½ feet in width. Each opening is closed by a sluice-gate turning upon a nearly central vertical axis. The panel on one side of the axis is made 2 inches wider than the other panel to facilitate the closing of the gate against the outgoing current. The working of the sluice is easily effected by opening a little valve in the wider panel of the gate, which reduces the water pressure on that panel below the pressure on the other panel, so that the gate revolves and places itself in a line with the stream as soon as it is released by a turn of the post, at the side, which retains it in place. The gate is shut by giving it a sideways push, after the little valve has been closed, so as to make the current act on the larger panel. The sill of the sluice is 11½ feet below the average bottom of the basin which is sloped down to the sluice.

A solid masonry wall, 16½ feet thick, has been carried right across the outer face of the foundations of the sluice so as to overlap the abutments, on each side, for a length of 26¼ feet, and carried from the sill down to the Kimmeridge clay, a depth of 54 feet. This wall was built to protect the foundations of the sluice from all danger of being undermined by the scouring current, and alone cost £13,200, out of a total expenditure of £34,000 on the masonry of the sluice. The gates and protecting draw-doors on the sea side cost about £5,600.

A volume of 654,000 cubic yards of water is discharged through the sluice in forty-five minutes, attaining a velocity of 26 feet per second. The sluice is situated at the north-western extremity of the basin, and opens into the entrance channel.

The inlet opening is placed near the eastern end of the northern embankment. The size of the opening has been made sufficient to enable the basin to be completely filled during the two and a half hours of nearly slack water that occurs at Honfleur directly after high water. The water at this period is comparatively clear, so

Digitized by Google

that by this precaution the rapid silting up of the sluicing basin is avoided. The inlet opening is composed of ten bays, separated by masonry piers 6½ feet in width. Each bay is 32 feet 10 inches wide, and is closed by three gates opening inwards and turning upon a horizontal axis on the apron of the weir, resembling in principle M. Thénard's system of movable weir. Each gate is 11 feet 1¾ inch wide and 7 feet 1¾ inch high. These gates are placed at such a level that when raised their top reaches the level of the highest tides, and when lowered they are 2 feet below high-water level, so as only to admit the clearest upper layer of water into the basin. Each gate is worked by means of a chain, one end of which is fastened to the gate. The chain from the gate passes in succession over two pulleys, of which the first has its axis parallel to the gate and the other at right angles to it. By this means the direction of motion of the chain is converted, on passing over the second pulley, into a horizontal motion parallel to the line of the gates. Then by using chains of equal length, having their other ends fastened symmetrically along a beam capable of moving backwards and forwards along a bridge placed across the piers of the weir, the gates can be moved in unison up or down by a movement imparted to the beam. Two of these beams are employed for working the thirty gates. Each beam is connected with a pair of conjugate pistons, working in two cylinders containing water, and communicating with a hydraulic accumulator which is the source of motion. The hydraulic machinery is placed on a broad pier in the centre of the weir. The hydraulic power acts merely as a brake when the gates are being lowered, and only imparts motion when the gates have to be raised. The cost of the inlet opening with the machinery amounted to about £44,000.

The total cost of the sluicing basin, including dredging and other supplementary works, amounts to over £200,000. It is, however, anticipated that these works will secure the maintenance of a proper entrance channel to the port and remove the impediments to its development.

L. V. H.

On the Measurement of Speed on Railways.

By Hr. Cörper.

(Electrotechnische Zeitschrift, part x., October 1881, pp. 366–9.)

This Paper refers to Schell's arrangements, by means of which the wheels of railway carriages close an electric circuit as they pass any place. They perform this operation at a number of places one kilometre apart. Successive marks are made on a slip of paper which is passing through a Morse writer at 40 or 50 millimetres per minute; the distance from mark to mark gives the speed of the train. It is to the actual wheel contacts that this paper is devoted. The original arrangement is described with figures. The

Digitized by Google

wheel on a carriage presses down a pivoted piece of steel turning a bell-crank on a stout post clear of the track, by means of a rod of iron 45 millimetres (1¾ inch) in diameter, which is carefully supported. The bell-crank lifts a vertical rod against the action of a spiral spring, and at its upper end this rod makes contact between two springs in an electrical circuit. This arrangement was largely introduced; but although many alterations were made, it was practically a failure, from the breaking of the rods, the destruction of the contact pieces, &c. The new arrangement, which works well, is quite different. The short end of a lever is placed underneath the rail, the other end being supported by a cord, which passes over a pulley and carries a weight. Pressed against this pulley, and on a steel axis, is a contact piece, to which is attached a ball of metal, by means of a strip of German silver. The pulley and this are only attached in a frictional manner. If the pulley rotates it only moves the contact piece a short distance along with it, as there are two stops, and the silver strip makes electrical contact on either side to which it may swing. The pulley and contact-piece are well supported on a girder attached to the sleepers, and a wooden box protects from the weather. By the passing of a train the rail is bent or shaken, so that the motion of the lever is sufficient to make the pulley move, and the frictional connection causes vibrations to be set up in the German-silver strip and ball, which increase as each new wheel of the train passes over, until the contact is made. In practice it is found that the action is immediate and to be depended upon, whether the yielding of the rail is great or small.

J. P.

The Rolling Stock of the St. Gothard Railway. By R. Abt.

(Organ für die Fortschritte des Eisenbahnwesens, 1881, p. 131.)

Although this railway is to be opened to traffic in 1882 the rolling stock is still wanting, and great discussion has taken place on the question, especially as to whether the engines are to be tank- or tender-engines. Whilst the existing Alpine lines are satisfactorily worked by tender engines, the frequency of good water stations on the St. Gothard, with other advantages, spoke strongly for the use of tank-engines. To decide this and other questions a careful study has been made of the locomotive working in Switzerland and other countries.

The total length to be worked by the engines of the St. Gothard line, including four branches, may be taken at 291 kilometres (180 miles). It was at first considered that the yearly traffic for the first ten years might be taken at 200,000 passengers and 400,000 tons of goods. Subsequently the estimate has been raised to about 250,000 passengers and 450,000 tons of goods; the

Digitized by Google

traffic being, of course, greater on the main line through the tunnel, and less on the branches.

With regard to the ratio between dead weights and paying weights, it appears that on the Swiss railways the number of seats occupied as compared with the number provided, taking the average from 1874 to 1879, was 30·2 per cent. On the St. Gothard line it was estimated that it would be 40 per cent. Again, the paying load for goods during the same years on the Swiss railways averaged 27·51 per cent. of the gross load. Owing to the heavy traffic of the St. Gothard Railway the proportion was estimated at 40 per cent. The dead weight of carriages per seat provided, for four-wheeled American cars, varies from 221 to 305 kilograms. For the carriages of the St. Gothard line it is 266 kilograms for four-wheeled and 186 for eight-wheeled carriages. On the whole a weight of 250 kilograms per seat may be assumed, which is equal to 605 kilograms per passenger, or 700 kilograms for passenger and dead weight together. Again, the average of the Swiss lines for goods wagons is 0·55 ton as the tare per ton gross weight hauled; and since only 40 per cent. of the gross capacity is utilised, the dead weight per ton of paying load is 1·375 ton, giving 2·375 tons as gross weight per ton of paying load. Hence results the following as the estimated traffic on the various divisions of the St. Gothard railway.

Line.	Traffic.	Gross Weight Hauled per Annum. Tonnes. (The metric ton = 0·9842 av. ton.)	Ditto per Day. Tonnes.
Immensee to Bellinzona . .	Passenger .	19,600	537
	Goods . .	187,500	3,254
Bellinzona to Chiasso . . .	Passenger .	175,000	480
	Goods . .	950,000	2,606
Bellinzona to Pino	Passenger .	175,000	480
	Goods . .	237,000	651
Bellinzona to Locarno . . .	Passenger .	105,000	288
	Goods . .	23,750	65

With regard to speed, the actual speeds on the Mont Cenis (gradient 1 in 33) are—

Express trains	15 to 18 miles an hour.
Ordinary „	14 to 16 „
Goods „	12 to 14 „

On the Brenner-Semmering the speeds are—

Passenger trains, average . . .	12 miles an hour.
Goods „ „ . . .	7 „

Herr Gottschalk holds that a goods engine on such lines, gra-

Digitized by Google

dient 1 in 40, should never exceed 9 miles an hour. Herr Hellwag fixed the conditions for the St. Gothard Railway as follows:—

In the valley,	max. gradient 1 in 100	{	Passenger trains	27	miles an hour.
		{	Goods	10	"
" mountains,	" 2·7 in 100	{	Passenger	13	"
		{	Goods	7	"
" tunnel,	" 2·58 in 100	{	Passenger	18	"
		{	Goods	9	"

With regard to the number of trains, allowing four hours out of the twenty-four for delays, and that passenger trains are thirty-one minutes, and goods trains sixty-three minutes, between Göschenen and Airolo, the possible number of trains per day would be twenty-five. If a crossing place were provided in the tunnel, the number could be raised to thirty-seven. With regard to the train loads, the terrible effects of a train breaking loose on such a line make it necessary to limit this according to the strength of the couplings. Even with the latest form of couplings it is considered that the total stress should not exceed 6½ tons. On the Semmering, on gradients 1 in 40 and curves of 200-yards radius, this stress is reached with goods trains of 200 tons. On the St. Gothard railway the gradient is 1 in 37, but the curves have only 300-yards radius. The result will therefore be the same, and the greatest weight of train must therefore be taken as 200 tons.

The locomotives necessary for conveying the traffic under these conditions for the first year were estimated as follows:

	12	engines, four-coupled,	25	tons adhesion	weight.
	19	" six "	38	"	
	17	" eight "	52	"	
Total	48	"	1,906	"	

For subsequent years the number was taken at eighty. The railway already possesses fourteen engines, and thirty-four new ones will therefore be required when the line is opened. In October 1880, the directors contracted for the supply of thirty-seven engines as follows:—

Six tank-engines, four-coupled, with a four-wheeled bogie, for the passenger trains on the valley sections: diameter of cylinder, 16½ inches; stroke, 24 inches; total heating-surface, 1,120 square feet; weight loaded, 42·7 tons; smallest adhesion weight, 22·5 tons.

Fifteen tank-engines, six-coupled, with a radial leading axle, for passenger trains on the mountain section: diameter of cylinders, 18·8 inches; stroke, 24 inches; total heating-surface, 1,302 square feet; weight loaded, 51·5 tons; smallest adhesion weight, 33 tons.

Sixteen tender-engines, with six-wheels all coupled, for goods trains: diameter of cylinders, 18·8 inches; stroke, 25 inches; total heating-surface, 1,378 square feet; weight loaded, 61 tons; smallest

Digitized by Google

adhesion weight, 38 tons. These engines have tanks for carrying 4 tons of ballast water, to bring up the adhesion weight, if required, to 42 tons.

The building of the heavy tank-engines was subsequently suspended.

The Council of Management of the railway have pronounced the above type of tender-locomotive to be ill-adapted to the railway, and the number insufficient. In comparing the two classes—tender- and tank-engines—it will be assumed that the tank-engines have 42 tons as adhesion weight at starting, with 10 tons on the leading axle, and the tender-engines that have the same adhesion weight, with a tender weighing 11 tons empty, and 23 tons full.

The following are the advantages of the tender-engine:—(1) Simplicity, (2) accessibility of parts, (3) lower level of centre of gravity, (4) greater range in choice of construction and dimensions, (5) constant load on the axle, (6) constant tractive force, (7) greater tendency to preserve the direction in case of derailment, (8) more room for water and coal, (9) consequent capability of taking a worse quality of coal, (10) less risk for men and passengers in accidents, from the presence of the tender, (11) use of strong tender-brakes.

The disadvantages are as follow:—(1) Overhang of the fire-box, causing objectionable and dangerous oscillations; (2) stiffness of the coupling between engine and tender; (3) great wear of the leading wheel flanges; (4) consequent wear of permanent way; (5) greater probability of derailment from this cause, and increased cost of maintenance; (6) large difference between the total weight and the weight utilised for adhesion, occasioning either the too heavy construction of some parts, or the carrying of ballast; (7) impossibility of completely inclosing the driver's stand.

On the other hand, the advantages of the tank-engine, with free leading axle, are as follow:—(1) Secure fixing of the boiler, (2) easy travelling, (3) safety on curves, (4) low resistance on curves, (5) uniform wear of the wheel flanges, (6) reduced wear of the permanent way, (7) possibility of inclosing the driver's stand.

The disadvantages are as follow:—(1) Variable load on axle, (2) variable tractive force, (3) confined space for driver, &c., (4) difficulty of access to some parts, (5) tendency to leave the direction in derailment, (6) loss of the tender-brakes.

As regards repair and maintenance, experience shows that a tank-engine costs more than a tender-engine, but not more than engine and tender together.

On the St. Gothard Railway it would not pay to burn inferior coal, as the freight is very heavy; hence the large coal space of the tender-engine is not needed. The leading bogie is not, of course, a feature of tank-engines alone, but its use is there much more easy and valuable. The question of tender-brakes has lost much of its importance now that many goods wagons have brakes, and that automatic continuous brakes are coming so rapidly into the field.

Digitized by Google

As to the efficiency of the engines, the gradient in the Kehr tunnel, on the Northern division, is 2·3 per cent. The continual wetness of the rails diminishes the resistance on curves, but also diminishes the adhesion, which must not be calculated at more than one-eighth. On the south side there are gradients in the open up to 2·7 per cent., so that the adhesion is the same on both sides. The resistance may be taken as 0·005 ton per ton of engine and train. Then the greatest weight hauled will be 187 tons, giving 122 tons of train-load for the tender-engine, and 135 tons for the tank-engine. The latter will, of course, lose tractive force, as its water and coal diminishes; but it appears that when it has lost 5½ tons its train-load will still be equal to that of the tender-engine.

The consumption of fuel may be taken as for the Brenner, viz., 94 kilograms (207 lbs.) per 1,000 ton-kilometres. The weight of the trains may also be assumed as the same, say 65 tons. This, with the tank-engine, gives a total weight of 110 tons. It follows that the whole length of 90 kilometres, from Erstfeld to Biasca, might be run with 900 kilograms (1,980 lbs.) of coal, and 7 cubic metres of water, and therefore without replenishing. There must always, however, be a stoppage before entering the tunnel, and water and coal can be easily taken in at that time. The weight of the goods trains may be taken at 120 tons, or 169 tons with the engine. This would require 10 cubic metres of water and 1,400 kilograms of coal. Coal and water must therefore be taken in once during the journey, whether tank-engines or tender-engines be used.

The lower dead weight of the tank-engine is, of course, a saving in point of fuel. It is calculated that on the mountain part of the line the saving would amount to 4,200 francs per annum. It appears, then, that tank-engines are equally efficient, safer, easier in running, and more economical, in wear and tear and in fuel, than the corresponding tender-engines. Since some tender-engines have already been ordered, it can only be suggested that half the stock should be in one form and half in the other.

As to the performance of the engines, the number of engines employed on the five main Swiss lines, in the summer of 1880, was as follows:—

In service 276, or 60·8 per cent.
In reserve 71, or 16·6 per cent.
Under repair 107, or 23·6 per cent.

Taking these in round numbers as 60, 20, and 20 per cent., it is found that the St. Gothard line will require fifty-one engines in all.

The annual mileage of the engines on the Swiss normal lines has steadily declined from 30,393 kilometres in 1874 to 24,839 in 1879. Herr Hellwag assumes that, on the St. Gothard line, the passenger engines will run 30,000 kilometres, and the goods engines 34,000 kilometres per annum, on the mountain section. The

Digitized by Google

question here is the time that the driver's firemen will practically work in each twenty-four hours.

On the Swiss railways the average time is 15½ hours per day in service, of which 7½ are actual running. In Germany the figures are 17·4 and 9·6 respectively. On the French East Railway they are 10 and 5 for express trains, 10 and 6 for passenger trains, and 12 and 7½ for goods trains. On the Belgian railways the average is 10½ hours in service. For the St. Gothard railway the hours of service may be assumed to be 14, of which 6 will be actual travelling, for quick trains, and 9 for slow trains; and this for two hundred and twenty days per annum. Assuming the speed to be 22 kilometres per hour for quick trains, and 12 for slow trains, it is found that the passenger engines will run 43,000 kilometres, and the goods engines 24,000 kilometres per annum, on the mountain section of the line. On the valley sections, where the speeds are 45 and 17 kilometres, the corresponding numbers will be 48,000 and 30,000 kilometres per annum. These figures are confirmed by the mileage of certain engines on the existing Swiss railways.

To obtain a high mileage for locomotives the following are the chief points to be attended to :—

(1) The engines must be properly constructed, and of good material.

(2) There must be a good distribution of the work, both for the drivers and the engines.

(3) There must be a well-equipped workshop, to make sound and rapid repairs.

As an illustration of No. 2, the total weight taken over the Mont Cenis line in 1878, exclusive of engines, was 1,024,500 tons, or 2,807 tons per day. This was hauled by thirty-seven engines, having a total adhesion weight of 1,798 tons. Adding the tenders at 20 tons each, the total engine weight working per day was 2,538 tons, to haul only 2,807 tons of train-load; in other words, the engine weight was 90 per cent. of the train weight, and three times as great as the paying weight.

A Table is given, which shows the amount of traffic which could be worked over the St. Gothard line by the thirty-one engines ordered, assuming their performances to be as above described. It appears that the performance of the passenger engines would be greater than that estimated as necessary on the line, but that of the goods engines considerably less. This difficulty might be overcome for a time, if the directors resist the temptation of opening the line with a large service of trains, which, in the case of a trunk line across a mountain chain, is quite unnecessary. It remains, however, that they should at once proceed with the design and construction of goods engines of a more powerful character. The type of these engines will be mainly determined by the three following conditions :—(1) Utilisation of the whole weight for adhesion; (2) fixed wheel-base of less than 3 metres; (3) load per axle of not more than 12 tons.

Digitized by Google

On the Austrian Southern Railway an eight-coupled engine, of 52 tons adhesion-weight, hauls a train of 200 tons total weight (the maximum which has been suggested for the St. Gothard line), including 25 tons for the tender. A 70-ton tank-engine, with twelve driving-wheels, would haul, with a smaller consumption of fuel, about 30 per cent. more of train-weight than the tender-engine; in other words, would take up in three trips a weight for which the other would require four. Such a double six-coupled engine would practically haul 300 tons across the mountain, and could thus convey the maximum daily train-weight of 3,250 tons in eleven trains; adding four mixed and ten passenger trains, the total number per day would be twenty-five; which could be worked without a crossing place in the great tunnel. The conclusion is that twelve-wheeled engines of this kind, more or less resembling the Fairlie type (of which three hundred have now been built) should be used for the St. Gothard line. [It is not stated how the difficulty of excessive strain on the couplings is to be got over.]

W. R. B.

On the Working of Local Passenger Traffic on Main Lines.

By Hr. v. Borries.

(Organ für die Fortschritte des Eisenbahnwesens, 1881, p. 183.)

The Author divides local traffic into two categories, suburban and inter-terminal. For the latter, *i.e.* local traffic extending over the whole length of the main line, the speed should not exceed 30 miles an hour on the level, nor fall short of 12 miles an hour. The interval between the trains should not be less than one hour. The number of seats must be capable of increase to suit the varying amount of traffic, and vans must be provided for luggage and mails. The minimum number of places should be one hundred, while the maximum must be such as will accommodate the largest volume of traffic which can possibly accrue. Hence the engines for this local traffic must not be too small. The carriages should be interchangeable between the local and through traffic, and should therefore be of the same leading dimensions, though they may be lighter in some parts, especially in the body. The train in North Germany may consist of one van, two combined second and third-class coaches, and three fourth-class coaches. There should be communication between the coaches, so that one guard may be sufficient for the whole train. Where the local traffic is very small, the van may be combined with the locomotive, and the train consist of a single third or fourth-class coach. This has been adopted with excellent effect on some parts of the Hanoverian railways.

The trains for suburban traffic, or omnibus trains as they may be called, should run at as short intervals as possible, and need

Digitized by Google

have no luggage-van. Such a system has not as yet been fully developed in Germany. It has generally to compete with tramways or road omnibuses. Its advantage over these lies in its greater speed. The speed therefore should not fall below 25 miles an hour, which is little more costly than that of 15 to 20 miles. Assuming the stations to be from 1 mile to 2 miles apart, the average speed will be about 15 miles an hour, or twice as great as that of tramways. If the tram-cars start at intervals of ten minutes, and the omnibus trains of half an hour, the average time of waiting will be 5 minutes for the former, and 15 for the latter. Hence for any length of journey beyond 2½ miles, the train will have the advantage in time; but in addition, people will know the times of starting for the trains, and will regulate their arrival at the station accordingly. This speed is that of the inter-terminal local traffic just described, and therefore omnibus trains can be interpolated between these without difficulty.

Two classes are all that is needed for the omnibus trains, as has been proved at Berlin. For the accommodation of market people, the seats in the third class should be lengthwise with free space in the middle. The ends of the cars, by which communication is made, may be utilised for smoking, which must not be allowed inside. Intercommunication between the carriages is necessary, both for the convenience of the public and of the train-men. The latter should not exceed two in number—one to drive an engine of 8 to 11 tons, and the other to act as guard. The brakes should be continuous. The cars may be of different character at different times of day, and should be lighter and smaller than those for through traffic. The objection to special classes of cars, from their requiring a larger number in reserve, does not hold in this case, because the lines are short, and close to the workshops. On the other hand, the frequent startings and stoppages make it very important to reduce the weight of the carriages. The dead weight may be about 6½ tons, with thirty-two seats for the second class, or fifty for the third class. The maximum weight of a train with one hundred and fifty third-class seats will then be about 30 tons.

A steam-car, or combined engine and carriage, is often recommended, and has sometimes been used in place of the above omnibus trains. Assuming the same traffic, the advantages and disadvantages of the two systems are as follow.

The steam-car saves two headstocks, four buffers, and two draw-gears with pipes of communication—a total weight of about 10 cwt. On the other hand, it cannot move backwards, and therefore requires the use of a turn-table. Again, its capacity is always the same, whilst with the omnibus train a carriage can be attached or detached as required. Each steam-car will have its own driver, and will therefore rest when the driver rests, whereas separate carriages can be run continuously. In order that the car may not be thrown out of use when the engine wants repair, the engine framing is now always made detachable from

Digitized by Google

the car; this detachment only takes place for serious repairs, and involves having a reserve pair of wheels, which weigh about as much as the parts that are saved. If the combined car is for any considerable traffic, its weight will be equal to that of an engine and carriage. It has of course the advantage of a greater adhesion-weight; but it appears that the engine for such trains will only utilise its full adhesion-weight if the speed is 7 miles an hour; and since the speed, even on the steepest gradient, is to be double this, it appears that only half the adhesion-weight will be utilised, even with the separate engine. It thus appears that, whilst the weight, cost, working expenses, and repairs are about the same in the two systems, there are definite disadvantages on the side of the steam-car, whilst its utmost capacity does not exceed one hundred seats. It seems, therefore, that it is only suited for very small traffic or very steep gradients, neither of which will be found on suburban lines.

Carriages for local trains.—Inter-terminal trains will be worked by three persons; a driver, who should be in command; a fireman, who should also look to the oiling of the carriages; and a guard to take charge of the tickets and luggage. The guard should have his compartment at the rear, and should there have the means of working the continuous brakes; his van should be divided into a mail compartment and luggage compartment, the heating apparatus for the train being placed between the two. The mail compartment, if not required, may be turned into a fourth-class carriage. Besides this, an ordinary train may contain two mixed second- and third-class coaches, one third-class, and two fourth-class, carrying altogether two hundred and sixty-two persons, and weighing when full 72 tons.

For omnibus trains, two coaches, without a van and with through communication, are all that is necessary. The driver should also act as guard, whilst the fireman works the engine. The oiling of the coaches, &c., will only be done at the terminus. There should be a continuous brake throughout the train, which should be regularly used instead of the engine brake. The seats should stand across the carriage, as, if they are lengthwise, the passage in the centre will be blocked up. Special market-wagons will be provided, with seats round the walls, and the middle space free for crates, milk-pails, &c. All these coaches should be built lightly, and of thin iron rather than of wood. They should weigh about 7½ tons, and the size of the axles, length of springs, &c., may be lightened in proportion.

Engines for local trains.—The weight of well-built, four-wheeled tank engines is given by the formula—

$$\text{Weight in tons} = 5 + 0{\cdot}3\,\text{H},$$

where H is the heating surface in square metres. This applies to engines on the Krauss system, where the frames and connections form part of the tank. Taking the driving-axle to carry 0·6 of the

Digitized by Google

weight, and that this never diminishes by more than 11 per cent., and taking as minimum coefficient of friction 0·15, there results 0·08 of the total weight as the maximum tractive force of the engine. The evaporation will be 6·15 lbs. of water per square foot of heating surface per hour, and the steam expended, 22 lbs. per indicated HP. per hour. Hence the power of the engine is 0·279 HP. per square foot of heating surface. On calculating from these data the speed at which the maximum tractive force will be developed, there results—

Heating surface .	square feet	107	215	322	430	538
Weight. . . .	tons	8	11	14	17	20
Speed	miles per hour	7	10½	12½	13¾	15

Hence it appears that with such engines the maximum tractive force can always be obtained without too great a reduction of speed.

The use of a single driving axle enables the leading axle to be placed in front of the cylinders, thus giving a large wheel base and a short boiler. The water-tank will be placed between the front axle and the fire-box, and made solid with the frames. The valve gear should be outside, and the leading axle should carry a single transverse spring, so that the engine rests on three points. The Hohenzollern type of locomotive is similarly arranged, but the wheels are coupled by rods passing close to the cylinders. The valve gear is therefore inside, and the Krauss arrangement of framing and water-tank is impossible. Hence such an engine, with 30 square metres of heating surface, weighs 18 tons, whilst a Krauss engine of equal power weighs only 14 tons. But taking the coefficient of friction at one-sixth, which is that adopted on the German lines, it appears that the weight on a single axle is sufficient to give all the tractive force required, unless at very low speeds and under special circumstances. It thus appears that neither the Hohenzollern engine nor the combined engine and car can gain any real advantage from their extra adhesion weight. The coupling of the wheels is not only superfluous, but hurtful. It increases the cost of construction and maintenance; the valve gear is awkwardly placed; the heavy coupling-rods require balance-weights, and, when the headstocks expand under heat, cause much friction and stiff running of the engine.

The compound locomotives of the Author are well adapted for this class of traffic; they have already shown a saving in fuel of nearly 20 per cent., and also a saving in wear and tear, through the more uniform pressure on the piston and reduced friction; thus they possess greater power for their weight and cost. The weight and heating surface proper for such engines, with other leading facts of their construction, are given.[1]

---

[1] These particulars will be found in a previous Paper of Hr. von Borries, abstracted in the Minutes of Proceedings, vol. lxiv., p. 402.

Digitized by Google

The following Table is considered to give the weight of train which may fairly be allotted to the various classes of engines, and these should be reduced by amounts up to 25 per cent. in bad weather.

Gradient.	Speed per Hour.	Weight of Engines, Tons.					———
		8.	11.	14.	17.	20.	
	Miles.						
Level .	25	42	90	138	186	234	Train weight, tons.
1 in 400	21	33	72	110	148	196	,,
1 in 200	18½	25	55	85	115	145	,,
1 in 100	15	17	39	62	85	108	,,

From this Table it will be seen that the 11-ton engines will be the ordinary type for omnibus trains, and the 17-ton engines for inter-terminal trains, the other types being adapted for special cases.

When the gradients are heavy and the speed may be low, it is advantageous to employ van locomotives as suggested by Elbel.[1] The length of the luggage compartment on the engine, in this case, is from 6 feet to 10 feet, and the total weight will be increased by about 3 tons. The saving therefore is not large, and the gain lies in simplifying the parts of the train. It will not apply to trains above 30 to 50 tons, and is therefore suitable for small branches rather than for main lines. Finally, the Author remarks that it is only by properly dividing the passenger traffic, that a general increase in the receipts from that traffic can be obtained, and that the foregoing suggestions are intended to facilitate such division. The concentrating of local traffic in local trains will also facilitate the through traffic, enabling it to be worked at greater intervals, with fewer stoppages, and at higher speed.

W. R. B.

The Laying of Gas-Mains and the Means of Discovering and Repairing Leaks in them. By M. Oppenheim.

(Journal des Usines à Gaz., 5th September, 1881, p. 1310.)

This Paper, to which the first prize was awarded at the last meeting of the "Société Technique de l'Industrie du Gaz en France," is divided into two parts, the first of which treats of various systems of mains, such as cast-iron mains with lead joints and with india-rubber joints and the so-called "Chameroy" pipes. M. Oppenheim considers that, for durability, cast-iron pipes are to be preferred, and that if coated with tar soon after casting their

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxi., p. 369.

Digitized by Google

durability is much increased. The chief objection urged against them is that, from the roughness of their internal surfaces, they cause loss of pressure from friction, and when they are coated internally with tar, the friction and formation of deposits are increased; if the tar is not dry when the pipes are laid it will remain in a liquid or semi-liquid state for a long time, which may be injurious to the illuminating power of the gas by depriving it of some of its benzine and other hydro-carbons and causing also naphthaline deposits. Where cast-iron spigot and socket pipes are used, M. Oppenheim prefers india-rubber to lead joints, but special forms of spigots and sockets are required for india-rubber joints. With ordinary spigot-and-socket pipes the india-rubber rings cannot be retained in position, and if the pipes move after laying there is nothing to retain the rings in their places. M. Somzée, the engineer of the Brussels Gas Works, has adopted two systems of pipes for india-rubber joints which remove this objection. In both systems the interior edges of the sockets are chamfered off at an angle of about 45°. In the first plan the spigots are slightly conical, a band is cast on the end to maintain the space between spigot and socket equal all round, and a second band keeps the india-rubber ring in position. In the second system the spigot is parallel and is divided into a series of grooves, its external diameter being nearly the same as the internal diameter of the socket. The india-rubber rings used are circular in section, fitting tightly on the spigots, and their thickness should be equal to double the space between the spigots and sockets of the pipes.

India-rubber joints are preferred to lead on account of their simplicity, flexibility and tightness, and the ease with which they may be made, or the pipes taken up if necessary. A lead joint is very rigid, and a small movement of the pipes will cause leakage. It is also difficult to lay a main on a curve with lead joints, but with india-rubber joints the pipes may be curved in any direction without injury to the joints. The chief economy of the india-rubber is in labour, which does not cost more than half that for lead. So far as the materials are concerned, much depends on the variations in the price of lead and india-rubber; but, in general, the total cost of the lead, yarn, red and white lead, &c., will exceed that of the india-rubber.

The "Chameroy" pipes, named after their inventor, are of sheet iron covered inside and outside with lead and a layer of bitumen or pitch over their external surfaces. They are cheaper than cast iron, and their smooth internal surfaces prevent much loss of pressure from friction. Their durability is not so great as that of cast-iron pipes; some have been found to deteriorate rapidly, while others have been found in good condition after thirty years' use. Where rapid deterioration has occurred, it has probably arisen either from the pipes having been damaged before laying, from injurious infiltrations into the ground, or from imperfectly purified gas. Carbonic and nitric acids are most injurious to lead. A variable quantity of carbonic acid generally exists in the atmo-

Digitized by Google

sphere, which readily attacks lead in the presence of moisture; and if the interior of a Chameroy pipe is long exposed before laying, deposits will take place. The sheet iron is also attacked by any ammonia or sulphur compounds left in the gas.

The description of pipes to be used the Author thinks should be governed by local circumstances. If the work to be done is so situated with regard to carriage or otherwise that the one system is cheaper than the other, preference should be given to the cheapest, bearing in mind, however, that a Chameroy pipe of a given diameter will deliver more gas than a cast-iron one of the same size. For example, if a main 600 metres in length has to be laid to supply on level ground 480 cubic metres (16,952 cubic feet) per hour with a loss of pressure at the extremity not exceeding 12 millimetres (0·47 inch), a Chameroy pipe of 244 millimetres (9·59 inches) diameter would be sufficient, while for the same purpose a cast-iron pipe of 260 millimetres (10·22 inches) would be required; and pipes of this diameter not being generally made, it would probably be necessary to use one of 275 millimetres (10·80 inches) diameter.

The main objects in laying down a system of mains should be to furnish the supply with the least possible loss of pressure, and to maintain a sufficient and constant pressure at all points. As the pressure varies with difference of level, the gasworks should, if possible, be situated at a point lower than the localities to be supplied, and the conditions of supply should be such that the speed of flow of gas in the mains should not exceed 2·70 metres ($8\frac{3}{4}$ feet) per second, and the minimum pressure at the burners should be 20 millimetres (0·787 inch).

In laying down a system of mains it is usual to start with a so-called leading main, keeping the same, so far as possible, below the level of the rest of the district; from this, branch mains of a smaller diameter are taken and other branches made from these, until the whole resembles a tree having the leading main for the trunk and the works for the root. When great differences of altitude do not occur, the branch mains should be connected together by cross mains, so that, in the event of any obstruction or accident occurring at any part, the supply may be obtained from other points. Where considerable differences of altitude exist, all cross mains from a low to a high level should be provided with valves or governors.

In some cases a distributing gasholder is established apart from the works near the centre of the district to be supplied, a main for feeding this holder being laid from the works; this is of great advantage for equalising the pressure; and a further improvement has been introduced by M. Giroud consisting of a small pipe, called a return main, from the gasholder back to the works governor, by which the slightest alterations of pressure due to variations of consumption are at once made to act upon the governor.

The second part of M. Oppenheim's Paper treats of the means for discovering and repairing leakages. Such leakages may arise from

Digitized by Google

the pipes being eaten through or broken, from defective joints or defective connections of the services, or in the services themselves. Assuming that the consumers' meters are registering correctly, and that the consumption of the public lamps is properly regulated, the Author proposes to estimate the amount of leakage and its probable locality by ascertaining the number of public and private burners on each main in use during the period of greatest consumption, and to estimate the quantity of gas required for their supply, having regard also to the loss by condensation; from which the loss of pressure at various points, due to this consumption, and assuming there is no leakage, can be ascertained, and by accurately observing the actual pressures at such points the loss by leakage can be inferred. Having thus determined where the greatest leakage is likely to be found, trials must be made by isolating portions of the mains by means of good bags, and fixing a meter with the inlet and outlet pipes on opposite sides of one bag, so that all gas passing into the isolated portion is registered by the meter. Proceeding in this manner, the defective points may be discovered and repaired.

Escapes at lead joints may be easily repaired by setting up the joints, and if broken pipes exist they should be removed. With Chameroy pipes the joints are more difficult to repair, but the pipes themselves can be easily repaired by soldering.

For services M. Oppenheim recommends lead pipes, but he admits that they are liable to be flattened by pressure and attacked by carbonic acid in the soil if not protected by being laid in wooden troughs and surrounded with pitch.

C. G.

Experiments in the Manufacture of Water-Gas.

By Dr. BUNTE, of Munich.

(Journal für Gasbeleuchtung, 1881, p. 521.)

This is a Paper read before the German Association of Gas and Water Engineers at Frankfort-on-the-Maine in June 1881. It is descriptive of Quaglio and Dwight's improved apparatus for making water-gas on Strong and Lowe's principle, and gives the results of some experiments made by the Author with an apparatus erected at the works of the Frankfort Gas Company.

The Author states that, according to theory, the transformation of solid into gaseous fuel is effected without loss of heat, the gas possessing exactly the same heating value as the original fuel itself. The decomposition of steam by carbonaceous fuel depends on two conditions:—1st, the existence of a certain temperature; 2nd, the presence of a sufficient store of heat. The temperature at which steam is decomposed by carbon is not exactly determined, but it is about 600° Centigrade. The chemical process follows one or other of two lines of action according to the quantity of heat

Digitized by Google

present in the substances themselves or extraneously provided. They are indicated by the equations

$$\text{I. } C^2 + 2H^2O = 2CO + 2H^2$$
$$\text{II. } C + 2H^2O = CO^2 + 2H^2$$

In the first case the result is a gas entirely combustible, composed of equal volumes of carbonic oxide and hydrogen, which is the water-gas in its theoretical constitution. In the second case the gas produced contains one-third of its volume of carbonic acid in conjunction with hydrogen. The aim in practical working is to produce the decomposition in accordance with equation I. and not by equation II. The two actions are distinguished by the difference in the amount of heat absorbed. For 1 cubic metre of steam there are absorbed by the first process 2,504 calories, by the second process 824 calories only. In the second case the total volume of the gas is three-fourths, and the volume of the combustible gas one-half that produced by the first process. Reduced to equal parts of carbon the heat absorbed by equation I. is 2,504, and by equation II. 1,648 calories per kilogram of fuel, the quantity of steam used being double in the second process, and the volume of combustible gas the same in both cases.

The production of carbonic oxide in carbonic acid depends upon the store of heat present during the process of dissociation.

The apparatus in question consists of a closed generator in communication with other rectangular chambers filled with fire-bricks, by which the heat developed in the combustion of the fuel is taken up. Air is blown in at the bottom of the generator, and the combustion completed by means of a second supply of air introduced at the top of the generator. When the contents of the chambers have become heated to a bright red heat the air-valves and outlet flue are closed and steam is blown in, which, passing first through the chambers in which the heat is accumulated, becomes superheated and afterwards decomposed by the fuel in the generator. The gas produced then passes by an outlet valve to the gasholder. As soon as the heat is exhausted the steam is shut off and the process of heating recommenced. The generator and chambers are constructed of fire-brick and are encased in iron.

The period occupied by one "run" was ten minutes, six minutes being occupied in heating, and four minutes in gas-making. By continuous working six runs per hour could be accomplished, but the average was only four owing to delay caused by clinkering, refilling the generator, &c. The mean production of gas was 21 cubic metres[1] per run, and 2,400 to 2,600 cubic metres per diem. The consumption of coke was 81·65 kilograms (179·63 lbs.) per 100 cubic metres of gas produced, or, allowing 20 per cent. of residue (ashes and clinkers) 65·32 kilograms of pure carbon.

In practice it is not possible to prevent the formation of a certain

[1] One cubic metre = 35·316 cubic feet.

Digitized by Google

quantity of carbonic acid, and the gas also contains nitrogen and traces of oxygen as the result of the products of combustion carried forward from the chambers D and E at the commencement of gas-making, and atmospheric air occluded in the chamber C. The constitution of the gas, as shown by a series of analyses after being collected in the holder, was as follows:—

	Per Cent.
Carbonic acid	7·3
Oxygen	0·7
Carbonic oxide	34·5
Hydrogen	50·0
Nitrogen	7·5
	100·0

From preceding remarks it will be understood that the gas does not possess the same constitution throughout the whole period of gasification. At the commencement of gas-making the evolution chiefly accords with equation I., but after the store of heat is diminished, the production of carbonic acid increases. This was shown to be the case by analyses taken during each minute of production, from which the percentage of carbonic acid appeared as follows:—

	1st Minute.	2nd Minute.	3rd Minute.	4th Minute.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
I.	6·0	9·0	12·2	14·1
	5·0	9·5	..	13·5

In addition to the experiments made with coke (from Cannel coal), others were made with coal dust (passed into the generator from a hopper). At the same time it was sought to produce illuminating gas by simultaneously distilling paraffin oil. The presence of so large a proportion of carbonic acid in the gas proved an obstacle to the success of the experiment, the illuminating power being almost entirely destroyed.

The Author then proceeds to calculate the loss of heat in the operations:—0·6532 kilograms of carbon being consumed for each cubic metre of gas produced, 0·6532 × 8,080 = 5,278 calories are developed. On the other hand the heat rendered latent in the gas is as follows:—

34·5 per cent. CO = 0·345 × 3,007 = 1,037 calories.
50·0 „ „ H = 0·500 × 3,088 = 1,544 „
2,581

deducting this from the 5,278 calories developed by the combustion of the fuel, there remain 2,697 calories or 51 per cent. loss, while 49 per cent. of the heat is contained in the gas produced. The sources of loss are—

1st. The temperature of the waste gases during the heating process. This averaged 660° Centigrade.

2nd. The temperature of the gas as it leaves the chamber C = 500° Centigrade.

Digitized by Google

3rd. The radiation from the outer surface of the oven. The temperature of the shell, which is of cast iron, reaches, after a lengthened period of working, 140° Centigrade.

4th. The temperature of the clinker and ashes when withdrawn from the generator, and also the cooling of the oven at night, when out of work.

The proportion of loss from each of these sources is calculated to be as follows:—

	Per Cent.
Loss through heating the chamber	23
" " temperature of the gas	3
" " radiation and conduction	11
" " withdrawal of clinker and interruption in working	14
	51

To reduce the loss and make the gas production economical, the Author considers that the heat of the waste gases should be arrested and returned to the oven by applying the principle of regeneration, and that the sides of the oven should be cased with non-conducting material to prevent radiation.

G. E. S.

Iron Ore from Amberg, Bavaria. By Prof. J. BAUSCHINGER.

(From Glaser's Annalen für Gewerbe und Bauwesen, 15th March, 1881.)

The Author gives analyses of the ore, and notes that the large proportion of phosphorus it contains prevented it formerly from being converted by the Bessemer process, and ten years ago it was used principally for the body of steel-headed rails rolled at Sauforst by the Maximilian Ironworks Company for the Bavarian railways. This company afterwards obtained iron from mines of their own at Sulzbach, Auerbach, and the neighbourhood, and the demand for Amberg iron ceased. When the dephosphorising process was discovered in England, steps were at once taken to see if it could not be advantageously applied to Amberg ore, of which 700 tons were sent to Rothschild's iron and steel works at Witkowitz in Moravia, and there converted into steel rails and boiler-plates which proved to be of admirable quality. Specimens were forwarded to the Author to be tested, and the results are shown in extended tabular form. A diagram gives at a glance the comparative results of experiments on various specimens of steel of English, Scotch, and German brands, and the produce of Amberg ore fairly holds its own with all of these. The following conditions are imposed by the managers of most German railways on materials supplied to them:—

For axles, the lowest permissible absolute strength measured on a normal round bar turned cold out of the axle, shall amount to

Digitized by Google

50 kilograms per square millimetre (31½ tons per square inch) of the original cross section, with a contraction of not less than thirty per cent. of the original section. For determination of the quality both conditions must be combined, and the two numbers found (absolute strength and contraction) must be added together and their total reach the number 90 (called the quality-number). Locomotive wheel tires must possess an absolute or tensile strength of at least 60 kilograms per square millimetre (38 tons per square inch), with a sectional contraction of at least 25 per cent.; tender and wagon-wheel tires a tensile strength of at least 45 kilograms per square millimetre (28½ tons per square inch), with a sectional contraction of at least 35 per cent., and the "quality-number" must in both cases be at least 90. Rails must have an absolute or tensile strength of at least 50 kilograms per square millimetre, with at least a sectional contraction of 20 per cent., and a quality-number of at lowest 85.

The Paper concludes with chemical analyses of five varieties of steel produced.

T. H. E.

On a Producer's Classification of Iron and Steel.

(Stahl und Eisen, vol. i., p. 1.)

The classification of iron and steel proposed by the German Railway Union[1] as a basis for the supply of railway material having given rise to considerable discussion among the producers of such material, a commission for the purpose of drawing up a revised scheme was formed by the Society of German Ironmasters; and at a general meeting held at Dusseldorf on May 28, 29, 1881, was adopted after discussion.

The commission deprecated the practice of using the contraction of the fractured area alone as a principal measure of the toughness of the material, and considered that evidence of greater practical value as to this property is to be obtained from the results of the falling weight and bending tests combined. After some preliminary instruction in the method of preparing test pieces, the classification of the tests is given as follows:—

I. Tests with Undivided Objects.

a. Cold tests. 1. External inspection; 2. Hammering; 3. Falling weight; 4. Direct loading. *b.* Hot tests.

II. Tests with Separated Pieces.

a. Cold. 1. Bending; 2. Punching; 3. Breaking; 4. Tensile.
b. Hot. 1. Bending; 2. Punching; 3. Forging; 4. Welding.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxv., p. 436.

Digitized by Google

The standards for the different classes of material are—

I. HOMOGENEOUS MATERIAL (Steel). RAILS.

a. Inspection.—As permissible variations in the linear dimensions, ± 3 millimetres in length, ± ½ millimetre in height, and ± 1 millimetre in breadth of flange.

b. Falling weight.—Tests to be applied to rail pieces that have not been either notched or bored, and whose ends do not project more than ½ metre beyond the bearings. The heights of fall of a weight of 600 kilograms, fixed for rails of different sections, are :—

a.	Weighing above	30	kilog. per metre and about	130	mm. high,	5	metres.
b.	„	27½-30	„ „	120	„	3·25	„
c.	„	23 -27	„ „	110	„	2·5	„
d.	„	20 -24	„ „	100	„	2	„

The test piece, 1 metre long, between the points of support in each case to receive two blows without fracture.

c. Loading Test.—For the different sections and weights given above, the weights to be supported without producing more than ½ millimetre permanent deflection are—

a. 17,500 kilograms; b. 13,500 kilograms; c. 11,500 kilograms; d. 10,000 kilograms.

d. Bending Test.—A length of rail, 1 metre, between the points of support to bend to 50 millimetres over both head and foot without fracture.

B. TESTS WITH PREPARED TEST PIECES.

a. Tensile Test.—Under the assumption that either the contraction of area or the longitudinal extension, but not both, will be used in judging the quality of the material, the Commission recommend the following tests :—

Bars of 200 millimetres long and 20 millimetres diameter shall bear a minimum load of 50 kilograms per square millimetre, with a contraction of 20 per cent. or an elongation of 12 per cent.

As regards further conditions in contracts for supplying rails, the Commission remark as follows :—

1. As limits of toleration in weight, 3 per cent. above and 2 per cent. below the normal amount, and of the excess weight about 2 per cent. should be paid for.

2. As regards maximum length, 9 metres, beyond which very few rolling mills are capable of working, and the risk of damage in transport is greatly increased.

3. About 5 per cent. of the rails shorter than the standard length to be received.

4. The guarantee for rails is fixed at five years, commencing on the 1st of January next following the date of delivery.

5. Rails worn out in regular traffic not to be replaced under the

Digitized by Google

guarantee. The guarantee on rails replaced to terminate at the same date as that on the original contract.

The number of rails reserved for testing not to exceed ½ per cent. of the whole amount.

2. Steel Tires.

a. Falling-Weight Test.—To endure three blows of a weight of 600 kilograms, falling 5 metres, without fracture.

Tensile test, with pieces 250 millimetres long and 20 millimetres thick.

1. Locomotive tires. Tensile strength, 55 kilograms; contraction, 25 per cent.; elongation, 12 per cent.

2. Tender and wagon tires. Tensile strength, 45 kilograms; contraction, 35 per cent.; elongation, 18 per cent.

The guarantee of two years not to be extended to tires subjected to the action of brakes, or to those worn out in regular traffic. The toleration in dimensions to be 1 millimetre per metre diameter. The number of tested pieces not to exceed ½ per cent. of the whole.

3. Steel Axles.

a. Falling-Weight Test.—To support without fracture upon a length of 1·5 metre between the bearings, six blows from a weight of 600 kilograms, as follows, the point of impact being changed after each blow:—

Two of 4 metres drop; two of 4½ metres; one of 5 metres; and one of 6 metres.

b. Tensile Test.—Maximum strength, 45 kilograms per square millimetre; contraction, 28 per cent.; extension, 15 per cent. Guarantee four years against failure through defective material or manufacture. Number of tests not to exceed ½ per cent. of total.

4. Steel Sleepers.

a. Cold Bending Test.—When flattened by moderately heavy blows of a steam hammer to stand bending round a radius of 75 millimetres to a loop without fracture. This test is only to be used when the form of the sleeper permits.

b. Tensile Test.—As for axles, with 30 per cent. contraction, or 15 per cent. elongation.

Permissible variation in weight, 3 per cent. above and 2 per cent. below standard; and in length, for cross sleepers, 15 metres; for longitudinal sleepers the same as for rails.

Number of tests not to exceed ½ per cent. of the whole, which is that adopted by the Rhenish Railway. Period of guarantee, two years.

5. Steel Fish-joint and Bearing Plates.

The tensile strength to be the same as for rails, but having regard to the great variety in the form of these articles in use the general application of other tests does not seem to be desirable.

Digitized by Google

B. Steel Constructive Material.

As sufficient experience in the use of steel for constructive purposes is wanting, the Commission does not consider it possible to recommend any special series of tests. In a general way, a tensile strength of 45 to 55 kilograms, with an elongation of 15 to 20 per cent., may be considered sufficient.

C. Steel Plates.

1. *Ship Plates.*—The tests recommended are those adopted by the German navy, namely, a tensile strength of 40–50 kilograms per square millimetre. Annealed plates should bend cold upon a radius equal to the thickness through 180° without fracture. Plates 260 millimetres long and 40 millimetres broad, raised to a cherry-red heat, and cooled in water at 28° Cent., to bend round a radius of 1½ thickness without fracture.

2. *Boiler Plates.*—Tensile strength 38–47 kilograms per square millimetre, with an extension of 25–18 per cent. Plates when soft to bend cold through an angle of 180° upon a radius of half the thickness. When hardened to satisfy the test given for ship plates.

The above tests are applicable to plates at least 5 millimetres thick; the testing of thinner ones not being considered necessary.

II. Welded Material. A. Bar Iron.

1. Rivet (best best) iron.

For this quality a tensile strength of 38 kilograms per square millimetre, with an extension of 15 per cent., is specified.

a. Cold Bending Test.—Pieces cut from flat bars from 30 to 50 millimetres broad, and not more than 16 millimetres thick, and round bars up to 30 millimetres in diameter, should stand bending into a loop whose inside diameter is equal to the thickness of the bar.

b. Hot Test.—When heated the test piece must bear doubling, and a piece of round iron two diameters long must bear reduction to one-third of its length without cracking.

2. Horse-shoe, nut, or (best) iron.

Tensile strength, 36 kilograms, with an extension of 12 per cent.

a. Cold Bending Test.—Flat section, not more than 16 millimetres thick, square and round, up to 30 millimetres diameter, to bend without cracking into a loop whose internal diameter is twice the thickness of the iron.

b. Hot Test.—The test piece, of the dimensions previously given, must bear bending into a loop whose inner diameter is equal to the thickness of the iron.

The above values for tensile strength and extensibility can only

Digitized by Google

be held to apply to manufactured objects whose thicknesses are not greater than those given under the cold bending tests. If therefore it is desired to test thicker objects, the test pieces must be reduced to the proper size by forging or rolling. The standard length for test pieces is fixed at 200 millimetres.

3. *Ordinary Bar Iron.*—The Commission does not consider it possible or necessary to introduce tests for this class of iron, as the differences between the make in the three principal German iron-making districts are dependent upon the local material employed, and cannot be eliminated.

B. Railway Material.

1, 2, 3. Sleepers, fish-plates, and bearing pieces.

The toleration in weight and dimensions to be the same as that given for steel sleepers.

Up to the present time railway managers have not specified any particular quality other than fibrous iron generally. Probably a tensile strength of 34 kilograms, and 10 per cent. extensibility, will be sufficient.

Should a cold bending test be required, it is proposed that test-pieces 30 to 50 millimetres broad, with rounded edges, should stand bending upon a radius of 13 millimetres as follows:—

Thickness,	8–11	millimetres,	50°
,,	12–15	,,	35°
,,	16–20	,,	25°
,,	21–25	,,	15°

Warm tests of these articles are not considered necessary, as they are never subjected to heating in use.

As experience shows that the quality of the material is not affected by punching or notching when cold, this should be permitted. The permissible variation in length to be ± 3 millimetres, and in weight ± 3 per cent.

It must be remembered that these articles cannot be sawn hot, as is sometimes required, but must be cut cold with a shearing machine.

4. Small iron material. Bolts, spikes, &c.

Usually a high quality of fibrous iron is specified for these objects. A tensile strength of 35 kilograms, with 42 per cent. extension, should be sufficient. The cold and warm bending tests should be the same as for best iron.

C. Plates.

The Commission consider it sufficient to lay down bending and tensile tests for the three best qualities of plates, leaving it to the consumer and producer to distinguish these by particular names.

Digitized by Google

It is to be remarked that many of the names hitherto used are no longer applicable, for instance, so-called charcoal plates are not now made from charcoal iron, &c. A general recognised classification, which should as far as possible express the quality, is much to be desired.

The following are the tests recommended :—

I. With Entire Objects.

Inspection.—Each plate, when examined on both sides, is to be free from blisters, cracks, and other marks of defective rolling; surfaces to be smooth and uniform.

In dimensions a variation of ± 10 millimetres in length and breadth. The weight to correspond to that form by calculation to within ± 5 per cent. in single plates, and ± 3 per cent. in larger quantities.

II. With Prepared Test-Pieces.

a. Bending Tests.—The hot bending test to be round a square edge; the cold ones round a cylinder 26 millimetres in diameter.

The angles through which the plate must bend red hot are, for—

	No. III.	No. II.	No. I.
With the fibre . . .	110°	150°	180°
Across	80°	120°	180°

Cold Bending Tests.

Thickness.	No. III.		No. II.		No. I.	
	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.
Millimetres.	°	°	°	°	°	°
6– 7	50	30	80	50	110	90
8– 9	45	25	70	40	100	80
10–11	40	20	60	35	90	70
12–13	35	15	50	30	80	60
14–15	30	12	40	25	75	50
16–17	25	10	35	20	70	40
18–19	20	8	30	15	65	35
20–21	15	5	25	10	60	30

The test is to be considered broken when a visible fracture appears in the metallic iron.

b. Tensile Tests.—The cuttings removed from the dome, man-hole or fire-tube plates to be used, where possible.

Fire-box and certain shell plates to be ordered 50 millimetres larger than the dimensions required, to allow the test pieces to be cut from them. The choice of length of the rectangular test piece between 150 to 200 millimetres, and of the section between 300–600 square millimetres, to be left to the maker.

Digitized by Google

The values in the following Table, in kilograms, are the breaking strain per square millimetre of the original section.

The extension is to be measured after fracture. The numbers given for strength and extensibility may vary by one, but the sum of both must be equal to that of the Table.

	No. III.		No. II.		No. I.	
	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.
Tensile strength, kgms.	33	30	35	33	36	34
Extension	7%	5%	12%	8%	18%	12%

The values given above are those adopted by the German Steam-boiler Inspection Commission at their meeting at Wurzburg, February 10, 1881.

D. Construction-iron.

By this term is meant the quality of rolled bar iron used in the construction of bridges and other large works.

A. Tests with undivided objects:—

1. *Inspection.*—The iron must be properly rolled, with smooth even surfaces, and free from cracks and cinder patches and other surface defects.

2. *Fracture.*—A flat bar, when nicked with a chisel and bent, must show a mainly fibrous structure, except in the case of bolt or rivet iron, where a fine-grained fracture may be required.

All further tests with full-sized objects are to be avoided, either as being inapplicable, or because the information required may more readily be obtained by working upon prepared test pieces. The hot bending test sometimes specified for flat and angle iron bars, of requiring the full-sized bar to bend hot through a certain angle, is uncertain, as the result depends mainly upon the skill of the operative making it; a good smith may apply it successfully to an inferior quality of material, while an unskilled one may fail with a better class of iron. The existence of redshortness, which this is intended to detect, may be more readily determined by the hot test upon prepared pieces.

B.—Tests with Separated Pieces.

According to its uses, iron for constructive purposes may be divided into the following four classes (I. to IV.) each corresponding to a particular requirement or a particular method of manufacture.

I. For angle and flat bars and plates mainly subjected to strain in one direction.

The plates included in this class are those employed in the tables of girders, tension rods, compression struts, &c.

1. *Cold bending test.*—A strip from 30 to 50 millimetres broad must bend, without fracture, round a cylindrical surface of 13 millimetres radius, through an angle varying with the thickness of

Digitized by Google

the plate. These angles are the same as those already given for sleepers and fish-plates (p. 488). This method of bending is to be preferred to the custom of bending into a loop of large radius more generally practised, as it may be applied mechanically in a more uniform way than can be done when the result depends in part upon the skill of the operator.

2. *Tensile test.*—Longitudinal breaking strain, 36 kilogrammes per square metre; extensibility, 12 per cent.: the test pieces to be from 300 to 500 millimetres long in the extensibilities to be observed upon a length of 200 millimetres.

These figures to apply only to bars whose thickness does not exceed 16 millimetres. Heavier bars should, as a rule, be avoided for such uses. When it is required to test the material of thicker bars, the test must be reduced to the standard dimension by forging or rolling.

3. *Hot bending test.*—Strips of the same dimensions as those of the cold bending test, when similarly treated at a cherry-red heat, must bear through the following angles according to thickness: Up to 25 millimetres, 120°; above 25 millimetres, 90°.

2. *Forge test.*—A strip of a flat or angle bar or plate, cut cold and heated to redness, must extend under the hammer to one and a half time its original breadth, without showing signs of separation in the iron. The radius of the hammer pane to be 15 millimetres.

II. Plates that are subjected to strains in different directions, or mainly to bending strains.

This includes connecting plates, corner pieces, gussets, the web-plates of girders, &c.

The cold bending test for these, in the direction of the fibre, is similar to that for the preceding class.

Across the fibre the angles are according to thickness—8 to 11 millimetres, 20°; 12 to 15 millimetres, 15°; 16 to 20 millimetres, 10°; 21 to 25 millimetres, 5°.

2. *Tensile test.*—When the plates are approximately square, the breaking strain is—

Longitudinal, 35 kilograms, with 10 per cent. extension.

Transverse, 30 kilograms, with 4 per cent. extension.

As these plates are mainly used as connecting pieces, the tensile strength may be taken 1 kilogram lower than in group I., as the constructor has to work mainly by the lower strength in the transverse direction. For the same reason the extensibility may be reduced from 12 to 10 per cent.

When the length of the plate is much greater than the breadth, the values are:

Longitudinal, 35 kilograms, with 10 per cent. extension.

Transverse, 28 kilograms, with 3 per cent. extension.

These plates are mainly applied in the webs of girders, and of cross and longitudinal bearers, whose length is at least eight times their breadth, for which purposes the transverse tensile strength of 28 kilograms is amply sufficient.

The hot bending and forge tests are the same as for group I.

Digitized by Google

III. Girder iron and flooring plates.

This includes all sections differing from single angle iron, such as I T [⅂ bars, sash bars, &c.; also buckled, corrugated, checkered, and similar plates.

Tensile test for girders:—

Longitudinal, 35 kilograms per square millimetre; extension, 12 per cent.

In this class of iron, no great transverse cohesion can be expected as the pressure in rolling in such directions is but small. It is customary to use [iron for connecting pieces, on account of its convenient shape, and in such cases a transverse strength, similar to that specified in group II. should be required. This, however, cannot be obtained under the ordinary conditions of manufacture, and it is therefore preferable in such cases to use a combination of flats and angles rather than a solid section.

For covering and flooring plates tensile tests are not necessary, the quality of the material being sufficiently evidenced in the manufacture. On account of their large amount of surface, their substance is more likely to suffer from rust than from loading.

IV. Rivet and bolt iron exposed to shearing strains.

To bend cold under the hammer to a loop equal to the diameter of the bar without cracking on the bend:—

Tensile strength, 38 kilograms per square millimetre; extension, 18 per cent.

The limits specified by the different railway authorities vary between 35 and 40 kilograms.

Hot test.—A piece two diameters long, when heated to the proper working temperature (that of hot riveting), to bear a reduction under the hammer to one-third of its length, without cracking at the edges.

The Commission does not consider it feasible to introduce tests for building girders, for the reasons that have been previously given under the head of common merchant iron.

H. B.

Malleable Cast Iron and the Annealing of Steel.

By M. FORQUIGNON.

(Annales de Chemie et de Physique, vol. xxiii., 1881, p. 433.)

Since the time of Reaumur who, in his classic memoir of 1722, first formulated the principles of the operation, the manufacture of malleable iron has become of great importance, but, in spite of the improvements introduced in its production, the chemical history of this product has still to be written.

Up to the present all that has been known is that malleable iron is cast iron deprived by oxidation of a part of its carbon, and thus approaching the state of steel or wrought iron.

Digitized by Google

To fully understand the experiments, attention is drawn to the following points:—

1st. All pig iron is not equally adapted for the process. Grey or highly manganiferous pig gives bad results. White or mottled pig made from the purest ores is preferable.

2nd. The softening of the iron applies nearly exclusively to small objects; the operation does not succeed well in the case of objects more than an inch in diameter.

3rd. The time for baking varies, according to size and quality required, from twenty-four hours to six days or more.

4th. The temperature of the furnaces is generally bright cherry red.

5th. Peroxyde of iron (powdered red hæmatite) is almost the only substance now used as cement.

The object of the Author has been to determine the chemical composition and tensile strength of numerous samples of malleable cast iron differing from one another either in composition, in place of manufacture, or in the treatment they had undergone, the effects of different substances used as cement, and also to find out in what way malleable iron differs from steel, wrought iron, and cast iron. In order to attain the objects in view the Author conducted a series of analyses of cast iron before and after its transformation, and experiments as to its physical properties, especially its elasticity.

The first series of experiments were made with cast iron heated in contact with powdered hæmatite. Secondly, heated with various substances such as charcoal, iron filings, silica, quicklime, calcined bones in powder, colcothar, and marine salt. Thirdly, in contact with various gases, such as hydrogen and nitrogen. These experiments proved that the softening of the cast iron does not result from the oxidation of its carbon, but that this oxidation, when it does take place, is purely accessory. By the simple action of a temperature sufficiently high, but inferior to its melting point, the white cast iron is destroyed or becomes carbonised, so to speak. A veritable amorphous graphite belonging to a particular variety is deposited abundantly through the whole mass of the bar, sometimes in the form of little visible agglomerations, sometimes disseminated or intimately mixed.

Instead of a combination there is now only a mixture of free carbon and free iron. The cast iron, deprived of a part of its combined carbon, is softened and its resisting properties are greatly modified.

The action ends here if the heating takes place in an inert substance like charcoal, but if the iron is in contact with a substance capable of burning or absorbing the carbon a secondary reaction takes place, the free carbon on the surface is burnt, a portion of the graphite from below comes to the surface and in its turn is destroyed. Manganese in the iron prevents softening by opposing the formation of graphite.

The Author sums up as follows:—

1st. A cast iron really malleable always contains amorphous graphite.

Digitized by Google

2nd. A cast iron may lose carbon and still remain brittle if graphite has not been formed, or if the existing quantity of graphite is not increased.

3rd. A cast iron may be rendered malleable without losing a sensible portion of its total carbon (when reheated in charcoal).

4th. If silicon is added to a manganiferous cast iron, the latter is improved by the reheating.

5th. Hydrogen and nitrogen combine with the carbon in the cast iron, which in this case alone can become malleable without the production of graphite.

6th. The breaking weight is always more than doubled, sometimes more than quadrupled, by the reheating; it increases with the length of the heating very rapidly at first, very slowly afterwards. Finally, malleable iron occupies a place intermediary between steel and grey pig; it differs from the latter by the special nature of its amorphous graphite and by its higher tenacity, and from the former by its lower ductility and large contents of graphite.

A series of experiments with steel similar to those with cast iron, viz. reheating in contact with various substances, confirmed the conclusions arrived at above.

The last few pages of this Paper contain a description of a small furnace by which very high temperatures can be easily obtained.

C. A. M.

Theory of the Manganese Blast-Furnace. By A. Ledebur.

(Zeitschrift des berg- und hüttenmännischen Vereines für Steiermark und Kärnten, vol. xiii., p. 287.)

The conditions necessary for the production of crude manganese metal (ferro-manganese) in the blast furnace are not very dissimilar from those required for highly graphitic iron; that is to say, highly basic slags, a high temperature in the hearth, very liberal allowance of fuel, in addition to sufficient manganese in the charge to allow of a considerable amount passing into the slag, which requires that the proportion of manganese to iron in the ore shall be considerably larger than in the crude manganese produced.

The investigation of a furnace producing this metal shows, however, that the work is done under very different conditions from those of ordinary iron smelting, as the higher temperature prevails, not only in the lower part of the furnace, but also in the higher part of the stack, which not unfrequently is red hot, while a great body of flame escapes at the throat.

These peculiarities, according to the Author, result from two principal causes. First, the extra consumption of fuel is due to the circumstance that the reduction of manganese from its lowest oxide (MnO) can only be effected by contact with solid carbon at a white heat, while the corresponding oxide of iron

Digitized by Google

(FeO) is susceptible of so-called indirect reduction by contact with carbonic oxide at a very much lower temperature. In the latter case the carbonic oxide is formed by the combustion of fuel with atmospheric oxygen before the tuyeres,

Where 1 kilog. of carbon with $\frac{4}{3}$ kilog. of oxygen burnt to $\frac{7}{3}$ kilog. of carbonic oxide develops	2,470 cal.
The $\frac{7}{3}$ kilog. CO oxidized to $\frac{11}{3}$ CO_2 in ore reduction produces further	5,600 „
The heat required to decompose sufficient iron ore to produce $\frac{4}{3}$ kilog. of oxygen (the amount required to burn the carbonic oxide) is approximately $\frac{4}{3}$. 4,200 = . .	5,600 „

Showing that by indirect reduction no demand is made upon the heat store of the furnace, the 2,470 cal. due to the original combustion of the fuel being available for the purposes of slag and metal fusion without diminution.

With direct reduction the conditions are different.

Here 1 kilog. of carbon burnt to $\frac{7}{3}$ kilog. CO by oxygen from the ore gives as before	2,470 cal.
But to release this oxygen the heat consumption is . .	5,600 „
Corresponding to an absorption of . . .	3,130 „

The total difference amounts therefore to 2,470 + 3,130 = 5,600 cal., which represents the amount of heat taken from the furnace for every kilogram of carbon expended in direct reduction, and which must be replaced by the consumption of an equivalent extra amount of coal. This explains the rapid cooling observed in furnaces when, in consequence of being too rapidly driven, the zone of reduction is raised by the heating of the upper part of the stack. In the case of manganese furnaces the result may be intensified by a larger amount of heat required for the reduction of manganous oxide, which is generally assumed to be about the same as for ferrous oxide, but is probably somewhat greater.

The second peculiarity of the working is due to the behaviour of the ascending current of carbonic oxide upon the manganese oxide, usually pyrolusite (MnO_2) in the ore. This, when heated to about 200° Centigrade in pure carbonic oxide, or to somewhat higher temperatures when the gas is diluted with nitrogen and carbonic acid, is reduced to manganous oxide, with a considerable development of heat. According to Professor Thomsen, the heat required to decompose MnO_2 into MnO + O is 21,511 cal. for each atom of oxygen, or is, for each unit of weight, 1,344 cal. The latter, however, when burnt with $\frac{7}{4}$ units of carbonic oxide develops 4,205 cal.; consequently 4,205 − 1,344 = 2,861 cal. remains as actual heat, or a larger amount than would be produced by the same quantity of free oxygen consuming coal at the tuyeres. The real rise of temperature will however be sensibly greater as

Digitized by Google

the oxygen derived from the ore will not be ballasted with nitrogen, as is that of the atmosphere. It is to this oxidizing action of the ore upon the furnace gases that the flaming throat of a manganese furnace is attributed by the Author.

As a remedy, the reduction of the manganese compounds in the ore to a lower state of oxidation is suggested, previously to smelting. This can be done by a simple calcination, but only at a comparatively high temperature, and the process is very slow. As a more advantageous and economical method, the heating of the ore in a current of blast-furnace gas is suggested. The furnace for this purpose might be a calciner of Moser's or Hasenclever and Helbig's pattern.

H. B.

Machine-made Muffles for Zinc-Smelting. By Léon Hiard.

(Revue universelle des Mines, 1881, vol. ix., pp. 184–195.)

In the manufacture of the muffles or pots, called also crucibles or retorts, which are employed for smelting zinc, the boring plan hitherto usual in Belgium—consisting in boring the inside out of a solid block of clay that has previously been moulded by hand to the external shape of the pot—is now being extensively superseded by M. Dor's process of moulding the clay to the required shape, both internally and externally, by the use of hydraulic presses. In the first press a compact homogeneous cylinder is progressively built up in a mould with clods of clay from the grinding mill, which are added in succession as the block becomes consolidated under the hydraulic pressure. In the second press the solid block is moulded into a hollow pot by the pressure of a smaller ram, by which the central portion of the mass is forced outwards into the annular space between the ram and the mould. In Ampsin's press the moulding pressure is exerted only by the central ram; but in Valentin-Cocq's more recent differential press an annular ram, surrounding the central ram, exerts a consolidating pressure upon the growing walls of the pot; this makes a better pot, though the process is rather slower than with Ampsin's press.

The comparison between the two modes of manufacture—by boring and by pressing—is considered by the Author to stand as follows:—

The bored pots are obliged to be shaped circular in transverse section; and the clay has to be in a softer state for making them. The material bored out exceeds 60 per cent., all of which has to be returned to the grinding mill. A loss of 2½ per cent. arises from the pots warping and cracking in the processes of drying and burning. The finished pots are more easily damaged by a blow from a furnace tool, or by a jolt in conveyance. They absorb more zinc from the charge smelted in them, and are themselves attacked

Digitized by Google

more rapidly by the ingredients of the charge. The number of pots used up per ton of ore smelted is estimated at 2½ to 3.

On the other hand, the pressed pots are shaped to any desired section, by using moulds and rams of that shape; they are made of drier clay, and hence stiffer kinds of clay can be used. The heavy pressure under which they are moulded makes them strong and close; there is no loss in drying, and the finished pots do not break so easily. When made on the spot, 1·6 pot suffices per ton of ore smelted; at other works, to which they have to be conveyed 10 miles by rail, 2 pots per ton are required, to cover damage from jolts in shunting. Hydraulic pressure has the advantage of squeezing out both water and air more thoroughly from the solid blocks formed for moulding the pressed pots, than can be done by ramming the material with the blows of stampers; and the Author suggests the desirability of using a pair of hydraulic rams to compress the block between them from both ends.

In the Liége zinc-smelting furnaces the average duration of the pressed pots is twenty-five days; each smelts rather less than ½ cwt. of ore per day. These pots are usually made of oval section, 12 inches by 9½ inches outside, with walls 1¼ inch thick and bottom 1⅝ inch; their length is about 4½ feet. The clay of which they are made is composed of ingredients mixed in the following proportions according to bulk, each ground and screened beforehand:—raw clay 35 per cent., sand 30, ptosherds 25, and coke 10 per cent.

A. B.

American Stamps for Gold and Silver Ores.

By F. Coignet.

(Bulletin de la Société de l'Industrie minérale, 1880, vol. ix., pp. 853–871.)

Whether constructed with timber or cast-iron framings, the stamps employed in the United States, west of the Rocky Mountains, for pulverising gold and silver ores, are arranged in sets of five heads in each coffer. Each coffer is supported upon a timber block resting on a massive wall of masonry or concrete, which extends all along underneath the row of coffers. An entirely independent foundation of timbers, laid on the levelled surface of the ground, carries the floorings as well as the whole of the upright framings, whereby these are preserved as far as possible from being jarred by the stamping. The coffer is generally of cast iron, in a single piece, weighing 24 to 30 cwts.; but sometimes in two pieces bolted together, the upper one being occasionally of strong sheet-iron. The grates, which are inclined outwards at top 15° to 20° from the vertical, are either of sheet iron, perforated with round or square holes ranging from 0·01 to

Digitized by Google

0·04 inch diameter or side, for stamping in water; or else of fine brass wire-gauze, containing 4,000 to 5,000 holes per square inch, for stamping dry. In either case, the grates usually wear out in a month's working. In stamping dry, the coffer has a grate at back as well as in front; the same plan might be adopted also in stamping ores of average hardness of the less precious metals, so as to facilitate the discharge of the pulverised stuff from the coffer, and thereby diminish considerably the proportion of slime produced.

The falling weight of each stamp—consisting of head, lifter, and collar—ranges from $4\frac{1}{2}$ to $8\frac{1}{2}$ cwt. The lifter is a turned wrought-iron rod of $2\frac{1}{2}$ to $3\frac{1}{2}$ inches diameter. The stamp-heads are of chilled cast iron or of Bessemer steel, and weigh $\frac{3}{4}$ cwt. to 1 cwt. when new. The anvils, also of hard cast iron or of steel, either fit into round recesses in the bottom of the coffer; or more commonly are made with a rectangular or octagonal base, and are simply placed alongside one another at the bottom of the coffer, and wedged in with dry wood keys.

The lifting cams are each double, to lift twice per revolution, and the curve to which they are shaped is the involute of a circle; as their plane of action on the lifting collar is out of line with the vertical axis of the lifter itself, rotation is thereby imparted to the lifter between each blow, causing both the stamp-head and anvil to wear uniformly over their whole face. For preventing the water from acquiring an oscillating motion endways in the coffer, the cams are so fixed on the cam-shaft or stamps-axle as to lift the five heads in succession in the order 1–3–5–2–4 in each coffer. The height of fall generally ranges from 9 inches, when head and anvil are both new, to $10\frac{5}{8}$ inches when they are worn out. The speed ranges from sixty to eighty blows per minute by each head, seventy being the most usual. Experiments made with stamps weighing only $5\frac{1}{2}$ cwts., and falling $8\frac{7}{8}$ inches, showed that twice as much stuff was stamped when running at one hundred blows per minute as at sixty blows; but while the higher would so far be the preferable speed, the cams curved to the involute of a circle would not then leave interval enough for the fall, and would require shaping to a quicker curve, entailing an injurious bumping action in lifting.

When stamping silver ores of average hardness at the Gould and Curry mine, Nevada State, new stamp-heads of 95 lbs. weight last for thirty-five days' work, exclusive of stoppages for repairs, and are worn down to only 35 lbs. weight; new anvils of 55 lbs. weight last from forty to sixty days, and wear down to only 29 lbs. The total loss of iron there amounts to 2 lbs. per head per day, and the corresponding quantity of ore stamped is nearly 23 cwts.; whence 1 ton of iron stamps over 1,200 tons of ore. In California the supply of water to the coffer in stamping gold quartz is as much as 3 gallons per head per minute, and even rises to half as much again if the stuff contains clay; but the Author considers the slime would settle better if the supply did not exceed $1\frac{3}{4}$ gallon, with stuff of average hardness. The stamps utilise about 70 per cent. of the power expended in driving them.

Digitized by Google

At eight mines in Nevada County, California, stamping hard gold quartz in water, the average power required per ton of ore per twenty-four hours was 0·88 HP.; and at five mines in Nevada State the power averaged 0·91 HP. for silver ores of average hardness, stamped in water; but at two mines in Nevada State, stamping dry, the power rose to 1·85 HP. and 2·42 HP. Tabulating and comparing the detailed particulars in these fifteen instances, the Author draws the conclusions that in stamping in water, ores of average hardness the duty is not proportional to the weight of the stamps: the lightest, weighing 4½ cwts., stamp more for the same power than any of the others, which range up to 8½ cwts. Also with the height of fall ranging from 8⅞ inches up to 12½ inches, it is the least height which gives the best duty. But with hard ores stamped in water the heaviest stamps, weighing 8 cwts., yield the highest duty. Ores of average hardness of the less precious metals—lead, copper, &c.—would not want stamps heavier than 3 cwts. for stamping fine, with 9 inches height of fall; then in stamping with water at seventy blows per minute, through grates perforated with holes 0·04 inch diameter, the Author considers a yield of at least 1½ ton per head, or 2 tons per HP., may be reckoned upon per twenty-four hours.

Stamps of 6 cwts. are estimated to cost about £1,160 for a battery of three coffers or fifteen heads, in oak framings, with horizontal expansive steam-engine of 25 HP., and two boilers, one of them in reserve. For stamps of 3 cwts., with 15 HP. engine, the cost would be £960; or £840 with fir framings instead of oak. With cast-iron framings in place of timber, the 6-cwt. battery would cost £920.

Inclusive of labour, repairs, coal, and materials, but exclusive apparently of interest and redemption, the total working expenses of the 3-cwt. steam stamps are estimated at 1*s.* 9¾*d.* per ton of ore; and at 9*d.* for stamps worked by water-power free of cost. The particulars of all the estimates are furnished in detail. Both the efficiency and the economy of the stamps would, in the Author's opinion, be materially augmented if the ores supplied for stamping were reduced beforehand by a stone-breaker to bits of the size of a nut.[1]

A. B.

Borings for Coal in the South of France.

By M. SARRAN.

(Bulletin de la Société de l'Industrie minérale, 1880, vol. ix., pp. 453–535.)

The Author describes four recent borings near Vigan, in the departments of Gard and Hérault in the south of France, for proving the coal of the Aveyron basin; and one at Peynier on the lignite basin in the department of Bouches du Rhône. All were

[1] Reference may be made to Husband's pneumatic stamp, described in the Proceedings of the Institution of Mechanical Engineers, 1873, p. 122 *et seq.*

Digitized by Google

executed by percussive and free-falling tools on Kind's system. Their sizes, costs, and other particulars were as follows:—

Borehole.			Fall of Tool.	Blows per minute.	Rate* per month.	Cost per yard.	Strata.
Name and Date.	Depth.	Diam. Top and Bottom.					
	Yards.	Inches.	Inches.		Yards.	£. s. d.	
Lasfons (Gard) 1874–6	261	15·4 13·8	12 to 14	45	19·17	11 18 9	Four lowest strata of Gard trias. Primary shales.
Navacelle (Hérault) 1874–7	602	16·9 12·2	8 to 17	30 to 60	15·75	10 16 0	Oolite, lias, trias. Conglomerate with mica shale, limestone.
Ste-Barbe (Gard) 1876	137	13·8 12·2	13 to 14	45 to 50	26·70	8 3 4	Lower strata of trias. Coal measures. Primary shales.
Desprats (Hérault) 1876	206	13·8 13·8	13 to 14	45 to 50	35·00	8 5 7	Triassic marls and limestone. Liassic marls.
Peynier 1877–9	350	18·5 12·2	13 to 14	45 to 50	25·15	8 5 7	Yellow and grey marls. Lignite measures.

* Including all stoppages for tubing and accidents.

After describing at considerable length, and illustrating by plan and sections, the geological features of the district round Vigan, the Author narrates in detail the progress of the work at each separate borehole, giving also complete figured sections of the successive strata passed through in each. At Lasfons, 3 miles south of Vigan, in passing through the sandstones and limestones at the bottom of the trias, the daily rate of progress was barely 1 foot, working night and day; yet the average rate per month in the last 190 yards of the hole, including these hard rocks, was over 23 yards. Navacelle borehole, 6 miles south-west by south from Lasfons, failed to meet with the coal measures, though they occur again some 20 miles further south-west. At Ste-Barbe, 2½ miles east of Lasfons, where a pit previously sunk and tubbed with timber for 90 yards had been abandoned through the water bursting in, the borehole was put down alongside to prove the strata below before resuming the sinking. Desprats borehole, 8 miles south of Ste-Barbe and on the eastern slope of a hill, passed through strata dipping at various steep inclinations, apparently vertical at a certain depth in the hole. The lignite basin in the department of Bouches du Rhône is estimated to contain 750 million tons of fuel, its area being nearly 200 square miles, of which only one-third has yet been leased for working. In Peynier borehole the main bed of lignite, reached at 350 yards depth, was

Digitized by Google

found to be 2½ yards thick, 5 feet thickness being of very good quality.

General Tackle.—The Author describes the arrangement of the boring tackle at the several boreholes, and the construction of the timber tower of 16 to 18 yards height, erected at each hole. For storing the rods, tools, and tubing, a well was sunk 7 to 12 yards deep, from the bottom of which the actual borehole was started. Steam winches were employed of 12 to 15 HP., each having two barrels: the rear barrel of 1 foot diameter had two speeds, and carried a flat hemp rope, 40 yards long and 6¼ inches wide by 1⅜ inch thick, which passed over a pulley at the top of the tower, and raised or lowered the boring tools fast or slow; the front barrel wound a rope of 1 inch for raising and lowering the clearing scoop. For the deep hole at Navacelle the power of the winch was doubled by the addition of a second steam cylinder. The quick speed was here used till a depth of 380 yards was reached; after which the other speed, seven times slower, was substituted. At 530 yards depth it took just two hours and three quarters to stop and clear the stuff out of the hole: more than one hour was occupied in drawing up the boring rods, and the same afterwards in letting them down again; in the remaining thirty-six minutes the clearing scoop was twice sent down to the bottom and brought up again. The iron boring rods being 11 yards long, the uppermost were raised or lowered with the slow speed at the rate of seventy-five seconds per rod, including the rise and fall of the rope coupling-socket, and the unscrewing and screwing of this and of the rod couplings; and for the lowermost, with the quick speed, the rate was thirty seconds per rod. The steam jumper or working cylinder was of two makes, each 12⅝ inches diameter, one having 40 inches stroke and the other 33½ inches. The latter was constructed for working expansively; but expansion had to be abandoned, because it was found the full pressure was required to be kept on to the very bottom of the stroke, in order to bump the end of the working beam against the buffer with jolt sufficient for making the kicker or catch release the boring tool.

Tools.—For holes 17 inches in diameter the steel chisel is made in a single piece weighing 7 cwts., 6¼ feet high and 5½ inches square in the shank; the blade is 2 to 2¼ feet high, 3 inches thick at top, and with a cutting edge 1 to 1½ inch thick. The tool head is of wrought iron, steeled at the hook or catch. A wrought-iron bar 10 feet long, carrying a four-ribbed guide or lantern, is interposed between the tool head and the chisel, and is united to both by conical screwed sockets, which have been found preferable to any other couplings. The entire falling weight giving the blow ranges from 10 to 11 cwts.; and the practical advantage of its being made up of three pieces screwed together is that, whenever the chisel gets jammed in the hole, one or both of the upper pieces can be removed by unscrewing, and the chisel can thereby be more readily liberated than if the whole falling tool were in one solid length of 20 feet and upwards.

Digitized by Google

Steel.—All the best-known makes of steel were tried by the Author for the cutting edge of the boring chisel; and the only two which gave him entire satisfaction were the Krupp steel, and the faggoted steel, branded with four oxheads, from Holtzer of Firminy (Loire). The Holtzer steel was supplied, either shaped to the full size of the whole blade, ready for welding upon the shank of the tool; or shaped to form only the cutting edge, ready for welding upon the upper portion or body of the blade. The latter plan is not recommended by the Author; for the labour involved in the bigger weld more than counterbalances the saving realised from wearing down the steel of the cutting edge to the last scrap. The Holtzer steel is tough, does not fly, and tempers readily; the Author had it tempered at roughly about cherry-red, but a higher heat did not produce the cracks that were found to occur with the other steels, particularly with cast steel. With cast steel too, whether used for the entire blade or for the cutting edge only, the results were very bad: the tempering, however carefully done, could not be relied on, and the consequences of its imperfection were apt to be very serious; a broken bit of steel left in the borehole retards the progress of the sinking for a long time, wears the chisel blades, and may cause serious accident, as was the case at Navacelle.

Disengaging Catch.—The kicker or liberating catch is made in the form of a bell-crank lever, rocking on a horizontal axis, with its tail or longer arm projecting horizontally; its shorter arm acts as an inclined strut to prop up the hook of the tool head when lifting the tool. The bearing surface of contact between the hook and the nose of the catch or strut is inclined to the horizontal at such a slope as to be about at right angles to the inclination of the strut when engaged; the slope enables the catch to become disengaged by the inertia of the tail under a moderate jolt, and yet to engage again readily when working as fast as 45 to 50 blows per minute. The proper slope is found by trial, and the angle is preserved by a template, so as to ensure its correct reproduction every time the catch or the hook requires refacing.

A minute detailed description is given of every portion of the boring apparatus and tools, illustrated by engravings with amply figured dimensions. It includes the working cylinder or jumper, and the boilers supplying it with steam; the working beam and its trestle; the boring rods, with lifting strap and lengthening screw for connecting them with the beam, and swivel attachment for rotating them in the hole; the forks and spanners for screwing and unscrewing the couplings; the scoop for clearing the pulverised stuff out of the hole; the various appliances used for dealing with accidents; the tools employed for obtaining sample cores of the strata passed through; the tubes for lining the hole, and the mode of putting them down; and the tools for enlarging the diameter of the hole, which last the Author considers still admit of further improvement.

A. B.

Digitized by Google

Timbering Underground Roads in Collieries. By H. Daburon.

(Bulletin de la Société de l'Industrie minérale, 1880, vol. ix., pp. 873–883.)

In the winning of coal seams under a tender roof, the ordinary mode of timbering the gob roads through the goaf behind the stalls or working faces is attended with the disadvantage that the weight of the roof, as it settles down on the pack walls, crushes the timber beneath it; the timbering has consequently to be renewed several times over, and the fallen roof has also to be cut down over the road for preserving the requisite headway. In some collieries, accordingly, the practice is purposely followed of timbering lightly at the outset, until the pack walls have become thoroughly consolidated under the full pressure of the roof upon them.

New mode of Timbering.—To obviate the difficulties thus experienced, in working a seam 4 feet thick under a very tender roof, the Author has had recourse to the expedient of tapering off the feet of the uprights or legs in the timber frames or trestles supporting the roof over the roadways. The fir legs are cut taper by a circular saw to a height of about 2½ feet from the bottom, and in addition two longitudinal saw-cuts are run up to the same height in the tapered length. The legs are thereby weakened in such a manner as ensures their gradually crushing down at foot under the increasing pressure of the roof; while their upper portions, together with the oak headtree or cap-piece forming the top of the frame, remain whole and sound, for permanently supporting the roof after it has finally settled down on the pack walls. The bevel is cut on the convex side of the leg, and that side is turned outwards towards the pack wall, so that the leg in crushing shall press outwards against the wall, instead of yielding inwards towards the road. The requisite headway is secured at the time of constructing the road, by cutting up into the roof to such an extra height as will allow for the full extent of settlement that subsequently takes place. The headtree of each frame, resting at its ends on the top of the legs, is further supported in the middle by a pair of slanting struts, notched into the legs at about the level of the top of the coal seam; and each leg is bolstered behind the notch by a short round billet of old timber packed in between the leg and the wall. The result of this mode of timbering is that the whole of the roof over the timbered roadway settles down bodily, retaining what little strength it originally possessed; and no subsequent repairs have been found to be required for keeping the road open. The cost per frame—including cost of timber, cutting the legs, and labour of fixing in place—is altogether from 15*d.* to 18*d.* The average wages for driving, packing, and maintaining the roads, have amounted to considerably less, per ton of coal raised, than had previously been paid for only packing and maintaining them, exclusive of the driving. The average consumption of timber per ton of coal raised has also been diminished

Digitized by Google

by about 2*d.*, through the saving thus effected in the timbering of the roadways alone.

Iron Rods for Roof Laths.—In place of the ordinary wood spiles, slabs, or laths, lying on the top of the frames and supporting the roof between, the Author has substituted wrought-iron rods 0·4 inch square, which are allowed to sag down between the frames to an amount equal to one-eighth or one-fourth of their length, so as to bring their tensile strength largely to the aid of their mere transverse strength. The ends of the rods are bent over by the smith to form eyes of about 1-inch inside diameter; these are turned upwards against the roof, and are wedged in tight between the roof and the frame headtree; where an iron rail set on edge is used for the cap of the frame, instead of a timber headtree, the ends of the rods jam fast behind the rail-head. The eyes have the advantage of giving the rods more elasticity to meet any excess of pressure from the roof they are supporting. The frames, being each pulled with equal force in opposite directions by the roof rods, are thereby strongly braced to one another. With frames spaced 3½ feet apart, the roof rods are cut in 4-foot lengths to allow for forming the eyes. On inclined roads eight rods per frame are employed, at a cost of about 18*d.*; on level roads six are sufficient, costing 13½*d.* With a proper tool the smithing of the eyes is done for 15*d.* per hundred rods.

This plan of supporting the roof was first tried in 90 yards' length of an air-way, where the roof was very bad and exerted a very heavy pressure. The headtrees of the frames were some of them of wood, and others of iron; several were broken under the weight of the roof, as were also some perfectly sound wood roof laths in the neighbourhood; but of the iron rods not a single one gave way. Subsequently the iron rods have been generally employed by the Author for the roof of all gate-roads that have to be kept open permanently; it has been extremely rare to find one broken, and the cost of maintenance is *nil*. The ends of the rods require to be keyed securely, which is best done with flat stones, or else with old oak wedges. To preserve them from rust, the rods are dipped hot in tar. Rods only ⅜ inch square have also been used in return air-ways, and are found thus far to stand equally well; but for the gate-roads it is considered more prudent at present, pending longer experience, not to use rods less than 0·4 inch square.

A. B.

Cleaning Coal by an Air Blast.

By Messrs. Basiaux and Léonard.

(Revue universelle des Mines, 1881, vol. ix., pp. 135–139.)

The use of an air blast for cleaning coal is the invention of Herr H. Hochstrate, manager of the Rhein-Preussen Colliery, Homberg, by whom it has there been practically carried out. The coal corves

Digitized by Google

from the pit are tipped over a Briart grating having bars 2 inches apart; and the stuff that falls through is fed by a screw-creeper into the open upper end of a sizing trommel or cylindrical screen, 5 feet in diameter and 14½ feet long, which rotates at 16 revolutions per minute on a shaft slightly inclined to the horizontal. The trommel has four sizes of mesh, commencing at the upper end with 0·27 inch, which is followed by 0·47 inch and then by 0·67 inch, and terminating with 0·87 inch mesh at the lower end; all larger stuff up to 2 inches size, falling out of the open lower end of the trommel, is conveyed away upon an endless travelling band, by which it is delivered into wagons without undergoing any cleaning. For each of the four meshes of the trommel is provided a blowing fan, running at 800 revolutions per minute in a casing 5 feet in diameter and 20 inches wide, and delivering a horizontal blast transversely beneath the trommel. The four sizes of stuff passing through the trommel meshes fall through the blasts, and are caught upon perforated plates, which slope gently downwards from the blast. Down these plates the stuff slides, impelled by the blast, which meanwhile blows all the slack out of it into a collecting chamber beyond. The bits of shale are heavy enough to fall through the perforated plate upon an endless band beneath, which carries them backwards against part of the blast's force, and delivers them upon a longitudinal travelling band, whereby they are conveyed away. Owing to their lightness the bits of clean coal, aided by the blast, are able to pass over the holes in the perforated plate, instead of falling through with the shale; they drop off the further end of the plate into a separate hopper beneath. The slack chamber is divided into three compartments by transverse baffle-partitions, so as to allow the duff to settle; and a jet of steam is introduced into the last compartment, to prevent any escape of even the finest dust. The slack settling in the first compartment is conveyed away by a screw-creeper, and delivered by a bucket-elevator into wagons which take it to the coke ovens.

Results of Working.—In treating with this apparatus 2,298 tons of stuff as it came from the pit mouth, the classification effected was as follows:—

a. Coal too big for the 2-inch grating	608·7	tons	= 26·5	per cent.
b. Stuff from open lower end of trommel	492·9	„	= 21·4	„
c. Shale	37·4	„	= 1·6	„
Not exposed to the Air Blast	1,139·0	„	= 49·5	„
d. Cleaned Coal, four sizes up to 0·87 inch.	504·6	tons	= 22·0	per cent.
e. Slack	514·1	„	= 22·4	„
f. Shale	140·3	„	= 6·1	„
Cleaned by the Air Blast	1,159·0	„	= 50·5	„

The cleaning here takes effect upon half the original quantity of stuff, and separates 6·1 per cent. of shale. But as the cleaned coal *d* is still too dirty, containing as much as 7 per cent. of ash—while

Digitized by Google

also the shale *f* is too rich, containing 45 to 50 per cent. of coal—it is intended further to clean the four lots *d* by washing them in a continuous washer: letting the stuff fall into an upright trunk, through which flows an ascending stream of water, with a current strong enough to carry off the coal by an overflow at top, while the shale settles down through the water to the bottom.

Advantages.—Although the coal is less thoroughly cleaned by the air blast than by washing, yet the stuff undergoes so much less handling, that both coal and shale suffer less breakage; and, instead of producing slimes too dirty to be used for coking, the air blast makes no slimes at all, but yields slack good enough for that purpose. Both the cleaned coal and the slack are all the better for being dry; and as no water is used, the work is not interfered with by a severe winter.

Cost.—The cost of an establishment for cleaning 500 to 600 tons per day is about £1,500, including the cleaning machinery, buildings, coke ovens, 25-HP. engine and boiler, and shafting, &c. At Rhein-Preussen Colliery the entire working expenses for cleaning 600 tons per day average four-fifths of a penny per ton, or only about one-third as much as washing would come to.

A. B.

Wire Ropes. By A. Garcenot.

(Bulletin de la Société de l'Industrie minérale, 1880, vol. ix., pp. 695–798.)

The substitution of wire for hemp ropes in winding shafts is generally attributed by the Author, who is engineering inspector of stores for the Anzin Company, to the increased depth of the pits, and to the inadequacy of the machinery for winding with hemp ropes. As the breaking strength of best round hemp ropes ranges between 5 and 6¼ tons per square inch of net section, while best round iron-wire ropes are from six to seven times as strong and about six times as heavy for the same net section, it follows that round ropes of equal strength are also of nearly equal weight per yard, whether made of hemp or of iron wire.

After describing minutely the construction of flat hemp ropes, and also of wire ropes both round and flat, the Author confines his attention to flat wire ropes, which for winding are sometimes made as much as 1,200 yards long, though ranging mostly between 400 and 800 yards long. By way of taper, the full sectional area is generally retained throughout half the length of the shorter ropes, and is succeeded by a smaller section in the remaining half; while in ropes of 600 yards and upwards three sizes are employed, each for 200 yards length and upwards:—the big end has eight to ten wires in each strand, the middle length one less, and the small end six to eight. The iron wire ranges from No. 16 to No. 11 Birmingham wire-gauge (0·071 inch to 0·118 inch thick), the usual

Digitized by Google

thickness being No. 14 or 0·087 inch. In ropes of steel or phosphor-bronze the wires are No. 16 to No. 14, and in small steel ropes even No. 17½ or 0·059 inch.

Flat Iron-Wire Rope.—As a fair example, a flat iron-wire rope of 700 yards length, suitable for winding from about 500 yards depth, is ordinarily composed of six hawsers, stitched together alongside; each hawser consists of four strands, which are laid with left-handed twist in three of the hawsers and right-handed in the alternate three; each strand commences with ten wires at the big end of the rope, and, omitting one by one, terminates with six wires at the small end; the wires are No. 14 gauge or 0·087 inch thick, and are laid spirally without twist around a core or heart consisting of a small strand of tarred or greased hemp. The stitching of the hawsers together is done by sewing them through by hand, in a zigzag direction, at 2⅜ inches pitch, with fifteen wires of No. 14 gauge; these wires are either laid singly side by side, as a thin flat band of 1·3 inch width, or are twisted together in threes, forming a narrower but thicker band of five round strands. The latter, or round stitching, is quicker though harder for the workman to do, and does not bind the two outside hawsers nearly tight enough to the inner ones. With the flat stitching, though always done much tighter than the round, the tightness of the several wires is often unequal; which interferes with the uniform stretching of the hawsers under the load in regular working, and is one of the principal reasons why flat ropes twist when hanging down the pit. The tighter flat stitching also materially increases the stiffness of the ropes, in comparison with the round stitching. Tables are given of the widths and thicknesses of the rope with the two kinds of stitching, at its big end, middle, and small end.

Load and Jerks.—The weight of the sample rope averaging about 14 lbs. per yard, the gross load upon it at the winding drum amounts to 8 or 9 tons, on starting without jerk to wind from 500 yards depth a loaded cage weighing 5 to 6 tons. The strain would thus be only about 7 tons per square inch of wire section. But in pits where the average speed of the cage is from 20 to 23 feet per second (14 to 16 miles an hour), the rope is often running at 26 to 30 feet per second (18 to 20 miles an hour) by the time all its slack has been taken up. It then starts the cage with a jerk, which brings the strain at the drum up to about 13½ tons per square inch, and stretches the rope nearly 1½ yard in the 450 yards depth. A rope exposed to such a jerk would work with perfect safety. A detailed investigation is given of the work thrown upon the individual wires in the rope, owing to their spiral form; of the pressure they exert upon the core of each strand; and of the pressure exerted by the strands upon the cross-stitching wires. The splicings of the wires almost always occur within the middle 200 yards of a rope 750 yards long. Testing proves that the loss of strength due to the splicings is about 10 per cent.; whence the desirability of using wires long enough to do

Digitized by Google

without splicing, and so to allow of making the rope nearly 10 per cent. lighter for the same strength.

Cross-Stitching Wires.—The pressures produced laterally upon the different kinds of cross-stitching by the bending of the flat rope in its passage over a pit-head pulley of 10 feet diameter are investigated and tabulated; they are smallest in the case of a single thickness or layer or flat stitching, and greatest with a double layer of round stitching. In winding upon the rope roll, each successive coil has to slip sideways, right and left alternately, so that its component hawsers may lie in the furrows between those of the next coil beneath. The strain thereby thrown on the cross-stitching is shown to be independent of the diameter of the component hawsers sewn together into the flat rope, and is directly proportional to the strain on each of them; whence a larger number of smaller hawsers in a flat rope is preferable to a smaller number of larger ones, as regards the durability of the stitching—a conclusion confirmed by experience. Allowing four to eight coils in reserve on the rope roll when the cage is at the pit bottom, an elaborate calculation is given of the continuously diminishing strains upon the successive coils in winding up, and of the corresponding strains on the cross-stitching. From the copiously tabulated results it is inferred that in a new good and well greased rope, of the dimensions already given, the tension upon the cross-stitching wires in the coils on the rope roll would range between 6 and 20 tons per square inch. Most flat wire ropes in France are sewn with annealed iron wire from the Franche-Comté Works, which has an average tensile strength of fully 20 tons per square inch, and stretches 25 per cent. before breaking. When coiled on the roll therefore, with the maximum strain of 20 tons per square inch upon the cross-stitching, the outside hawser overhanging the coil beneath will have a very great tendency, even in a new rope, to part company from its neighbour, wherever not kept close up to it by the forks or guard arms of the roll. However small the lateral clearance between the roll arms and the sides of the rope, the outside hawsers will thus gape from the rest of the rope when winding upon the roll, particularly at the parts corresponding with the starting of the cage from the landing places in the pit; and in lowering the cage the hawsers will be closed up together again by the tension upon the rope as it uncoils from the roll. Moreover the minute stretching of the rope strands, every time the load of the cage comes on them, must inevitably cause friction between themselves and the cross-stitching wires, with consequent wear of both. The stitching gives way first, and ropes often come unsewn through long lengths. Hence the necessity for keeping flat wire ropes well greased in working, and for carefully examining them often enough to guard against rusting.

Experiments on Strength of Wire.—In twenty-two voluminous tables, with copious comments, are given the details of an extensive series of experiments upon different kinds of wire employed for ropes:—steel wire and iron wire, each galvanised and non-

Digitized by Google

galvanised; iron wire annealed; and phosphor-bronze wire, both unannealed and annealed. The wires were procured from various places, including Sheffield, Birmingham, Manchester, Cologne, Franche-Comté, and Anderlecht-lez-Bruxelles. They were tested not only for tensile strength and stretching, but also by torsion, and by bending backwards and forwards at right angles on an edge rounded with 0·2 inch radius; they were flattened out under the hammer into thin ribands, and were also hammered square, as a test of freedom from liability to splitting or cracking. The general conclusion drawn by the Author is, that steel wire is the most advantageous for the rope strands; while the annealed iron wire from Franche-Comté, or annealed mild-steel wire, forms the best sewing for flat ropes. For the strands of winding ropes, whether flat or round, the steel wire should possess a tensile strength of from 70 to 95 tons per square inch, taking no permanent stretch under 30 to 45 tons per square inch, and stretching only 2 to 4 per cent. before breaking.

For convenience of comparison, the arbitrary Nos. of the French and English wire-gauges, equally barbaric and mutually incommensurable, are tabulated side by side, with their equivalent sizes in millimetres.

A. B.

Steel Wire for Ropes. By ALBERT BONNAUD.

(Revue universelle des Mines, 1881, vol. ix., pp. 323–339.)

The manufacture of steel wire having lately been started under the Author's management at the Firminy Steel and Iron Works (Loire), independent engineers of eminence were called in to test the three qualities of wire here produced for rope-making, which are as follows. (I.) *Iron wire* from pig metal, intended to supersede with advantage the best makes of charcoal-iron wire, such as those of the Berry district; and to possess a tensile strength of 44 to 54 tons per square inch; and to be flexible enough to stand bending backwards and forwards at right angles, over an edge rounded with 0·4 inch radius, at least 12 to 14 times for wire of No. 14 gauge or 0·087 inch thickness. (II.) *Martin Steel wire*, to carry 80 to 90 tons per square inch, and to bend at least 8 to 10 times. (III.) *Crucible Steel wire*, to carry 90 to 100 tons per square inch, and to bend at least 8 to 10 times. In comparison with these was also tested charcoal-iron wire from Bigny (Cher), which is the best make of the Berry district and perhaps even the best that is known in France.

The wires were all tested for tensile strength, both under a steady pull and under a jerk; and for stretching, bending, and twisting. They were all of No. 14 gauge, and the tensile tests were made on lengths of about 16 inches: except the jerk tests, for which a length of 7 feet was suspended vertically, carrying a

Digitized by Google

dead weight equal to about one-tenth of the breaking load; a monkey or runner, weighing 2·20 or 7·17 lbs., and sliding freely on the wire, was let fall from a height of 6½ feet, and struck the suspended weight with blows which were repeated till they broke the wire. The bendings backwards and forwards at right angles were counted as follows:—the wire being held upright between a pair of jaws having their edges rounded to 0·4 inch radius, the projecting portion was bent over horizontally to the right, which was counted as No. 1 bending; in No. 2 it was brought back to the upright and bent over horizontally to the left; and so on. In the torsional tests, the number of revolutions was counted, through which the wire carrying a suspended weight could be twisted before breaking; the length twisted is omitted to be stated definitely, but was apparently about 16 inches. The results are tabulated as follows:—

Wires of No. 14 gauge = 0·087 inch thick.	BIGNY Charcoal-Iron Wire.	FIRMINY Wire.		
		IRON. I.	STEEL. II.	STEEL. III.
Average tensile strength, tons per sq. inch	46 tons	57 tons	86 tons	102 tons
Stretch on breaking, per cent. . . .	0·30	0·37	0·91	0·75
Flexibility, bendings at right angles .	18 times	19 times	20 times	28 times
Torsion, number of twists	21 revs.	41 revs.	10 revs.	7 revs.
Suspended weight, lbs.	66 lbs.	75 lbs.	132 lbs.	132 lbs.
Jerks, number to break	4	16	40	40
Falling weight, lbs.	2·20 lbs.	2·20 lbs.	7·17 lbs.	7·17 lbs.
Height of fall, feet	6½ feet	6½ feet	6½ feet	6½ feet
Suspended weight, lbs.	68 lbs.	70 lbs.	138 lbs.	138 lbs.

The jerk tests, which seem to have been made but seldom previously, show how decidedly superior is the strong steel wire to the best iron. The fractures showed that no change in the quality of the metal was produced by the jerks.

A further set of tensile tests, on lengths of about 4, 8, 12, and 16 inches, are tabulated for each quality of wire. In these again, contrary to what is sometimes believed to be the case, the strong steel wires always stretched more than either of the iron wires.

In regard to the effect of temperature, the four qualities of wire were tested at 32° Fahr., and also after repeated sudden alternations from 32° to 250° and back again. Neither their tensile strength nor their flexibility was found to be materially affected thereby.

Lest it might be fancied that the high tensile strength of the steel wire might be due to extra hard drawing, and consequently that such wire might not prove so safe for ropes, the Author tabulates a series of experiments made by himself on iron wire from pig metal, drawn soft enough to be as like charcoal-iron wire as

Digitized by Google

possible, and on the steel wire that carries 80 to 90 tons per square inch. Four samples of each were taken from each of the three principal stages of the manufacture :—(*a*) rod from the rolling mill, ready for drawing; (*b*) unfinished wire, drawn down as far as it could be before annealing, and then annealed in the case of iron, and specially tempered in the case of steel; (*c*) finished wire, drawn down to No. 14 gauge or 0·087 inch thickness. In addition two samples (*d*) of each finished wire were afterwards annealed. The results under these several conditions—*a*, *b*, *c*, *d*—ranged between the following limits :—

Samples about 16 inches long. Finished Wire, No. 14 gauge = 0·087 inch thick.		FIRMINY Wire.	
		IRON (soft).	STEEL II.
TENSILE STRENGTH, tons per square inch.	*a*	23·5 to 30·5	57·1 to 69·8
	b	27·3 to 29·8	80·6 to 96·6
	c	38·1 to 40·6	98·4 to 104·8
	d	31·1 to 31·1	53·3 to 56·5
STRETCH on breaking, per cent.	*a*	7·46 to 16·79	6·17 to 7·00
	b	22·00 to 22·00	2·95 to 5·67
	c	0·31 to 0·74	1·18 to 1·75
	d	20·52 to 20·60	6·83 to 8·00
FLEXIBILITY, number of bendings at right angles.	*a*	8 to 11	2 to 4
	b	20 to 22	4 to 10
	c	21 to 29	16 to 37
	d	31 to 31	12 to 13

From a comparison of the results (*b*) and (*c*) it is clear that the drawing process certainly imparted no greater augmentation of tensile strength to the steel than to the iron; it was chiefly the flexibility of the steel wire which was thereby increased. Comparing indeed the results (*d*) and (*a*), it is seen that the compressing effect of the draw-plate was really much more severe on the iron than on the steel: for, even after a very thorough annealing, the finished iron wire still retained a higher tensile strength than the same material had originally possessed before it had undergone any drawing at all; whereas, after annealing the strong finished steel wire, its tensile strength fell off, as would naturally be expected, to rather below what it had originally been. It is indeed by taking advantage of the characteristic property of steel—namely by hardening and tempering it—that the value of its high tensile strength is realised, in combination with a fair amount of flexibility; as in the case of the strong steel wire of English and German make.

The cost of the Firminy steel wire is double that of the Bigny charcoal-iron wire; but as its tensile strength is also double, a rope of steel wire will be only half as heavy for the same strength; the cost of the ropes is therefore equal. The steel ropes have the

Digitized by Google

advantage of being safer, and more flexible in consequence of their smaller section; they produce less chafing, both upon the winding machinery and within themselves; and when well looked after they ought to last longer, since friction has less wearing effect on them.

A. B.

Experiments on the Work done by Reaping Machines.

By Dr. Hartig.

(Der Civilingenieur, 1881, p. 369.)

This Paper gives the results of dynamometrical experiments made with reaping machines, in 1879, at Lockwitz, near Dresden. The dynamometer used was one of Bental's; in it the tractive force was measured by the compression of a spiral spring. This spring was connected to a mechanism for taking work diagrams, and also to a mechanical disk-and-wheel integrator, driven off one of the axles. It was found by careful experiment that the integrator readings had to be multiplied by 1·285 to correct the effect of slip.

The machines tested were:—

1. W. A. Wood; one-horse, hand rake, combined mower and reaper.
2. McCormick; two-horse, self-raking reaper.
3. Samuelson; two-horse "Omnium" self-raking reaper.
4. Buckeye; two-horse self-raking reaper.
5. W. A. Wood; two-horse reaper, with patent self-raker.

The principal results of the tests are contained in the following Table:—

Number.	Rate of Travel.	Tractive Resistance.		Tractive Efficiency.	Breadth of Cut.	Area Cut per Hour.	Area Cut per HP. per Hour.
		Cutting.	Not Cutting.				
	Ft. per sec.	Lbs.	Lbs.		Ft. Ins.	Acres.	Acres.
1	3·02	159·2	100·5	0·37	3 5⅛	0·861	0·969
2	4·26	366·7	285·8	0·22	4 2	1·469	0·534
3	4·46	314·9	200·4	0·36	4 7½	1·706	0·665
4	3·81	340·2	250·3	0·26	4 8½	1·476	0·618
5	4·86	296·1	216·1	0·27	4 6⅜	1·633	0·687

The Paper contains full illustrations and descriptions of the dynamometer and reaping machines.

W. P.

Digitized by Google

American Milling Methods. By ALBERT HOPPIN.

Read before the meeting of the Pennsylvania State Miller's Association at Pittsburg, Pa.

(Scientific American Supplement, 1881, No. 303, p. 4826.)

The Author remarks that the chief cause of improvement in American milling machinery was the great difficulty of milling hard spring wheats by the old methods. Had it been as easy to raise good winter wheat in Wisconsin and Minnesota as in Pennsylvania and Ohio, or as easy to make white flour from spring as from winter wheat, purifiers and roller-mills would not have been heard of for years to come.

The different methods of milling at present in use may be generally divided into old style, new process, and gradual reduction; or, better perhaps, into the German division of low milling, half-high milling, and high milling. Old-style milling was in general use in America up to 1870, and is still followed in the great majority of small custom or grist mills. It is very simple, consisting of grinding the wheat as fine as possible at the first grinding, and separating the meal into flour, superfine or extra, middlings, shorts, and bran.

The new process may be said to be half way between the old-style and gradual reduction. In it millstones are used to make the reductions, which are only two in number; in the first the aim is to make as many middlings as possible, while cleaning the bran reasonably well, and in the second to make the purified middlings into flour. In the most advanced mills which use the new process, the bran is reground, and the tailings from the coarse middlings, containing germ and large middlings, with pieces of bran attached, are crushed between two rolls. These can hardly be counted as reductions, as they are simply the finishing touches, put on to aid in working the stuff up clean, and to permit of a little higher grinding at first.

The two essential qualities of a good marketable flour are colour and strength. It should be sharply granular, and not feel flat and soft to the touch. A wheat which has an abundance of starch, but is poor in gluten, cannot make a strong flour. This is the trouble with all soft wheats, both winter and spring. A wheat which is rich in gluten is hard, and, in the case of hard Minnesota wheat, has a very tender bran. It is comparatively easy to make a strong flour, but it requires very careful milling to make a flour of good colour from it. Probably the wheat which combines the most desirable qualities is the red Mediterranean, which has plenty of gluten and a tough bran. By careful milling, a wheat naturally deficient in strength may be made into flour having all the strength there was in the wheat originally, and of good colour.

The idea of gradual reduction milling was borrowed from the Hungarian mills. There is, however, this difference between the

Digitized by Google

two, that in the latter, when fully carried out, the products of the different breaks are kept separate to the end, and a large number of different grades of flour made, while in the system, as applied in America, the separations are combined at different stages, and usually only three grades of flour are made, viz., patent, baker's, or, as it is termed in Minnesota, clear flour, and low grade or red dog. In the largest mills the patent is often subdivided into first and second, and they may make different grades of baker's flour, these mills approaching much nearer to the Hungarian system, though modifying it to American methods and machinery. In mills of from three to five hundred barrels daily capacity, it is hardly possible or profitable to go to this subdivision, owing to the excessive amount of machinery required.

Gradual reduction consists in reducing the wheat to flour, shorts, and bran, by several successive operations technically called breaks, each break leaving the material a little finer than the preceding one. Usually five breaks are made, though six or seven may be used; but it is preferable to keep the process as simple as possible, for even at its simplest it requires a good wide-awake thinking miller to handle it successfully.

The Author gives the programme of a mill of one hundred and fifty barrels maximum daily capacity, designed to work on mixed, hard, and soft spring wheat. The main principles are the same, whether applied to spring or winter wheat.

The wheat is first cleaned as thoroughly as possible, to remove all extraneous impurities, care being taken to scratch or abrade the bran as little as possible. The ultimate purpose of the miller being to separate the flour portion of the grain from dirt, germ, and bran, it is important not to get any dirt or fine bran speck, or dust mixed in with the flour at any stage, for if it does it cannot be got rid of again.

After the wheat is cleaned, it is by the first break or reduction split or cut open, in order to liberate the germ and the impurities in the "crease." As whatever dirt is liberated by this crease becomes mixed with the flour, it is desirable to keep the latter as small as possible. Indeed in all the reductions the object is to make as little flour and as many middlings as possible, for the reason that the latter can be purified, while the former can not, at least by any means at present in use. After the break the cracked wheat goes to a scalping reel, covered with No. 22 wire cloth. The flour, middlings, &c., go through the cloth, and the cracked wheat goes over the tail of the reel to the second machine, which breaks it still finer. After this break the flour and middlings are scalped out on a reel covered with No. 22 wire cloth. The tailings go to the third machine, and are still further reduced; then through a reel covered with No. 24 wire cloth. The tailings go to the fourth machine, which makes them still finer; then through a fourth scalping reel, the same as the third. The tailings from this reel are mostly bran, with some middlings adhering; they go to the fifth machine, which cleans the

Digitized by Google

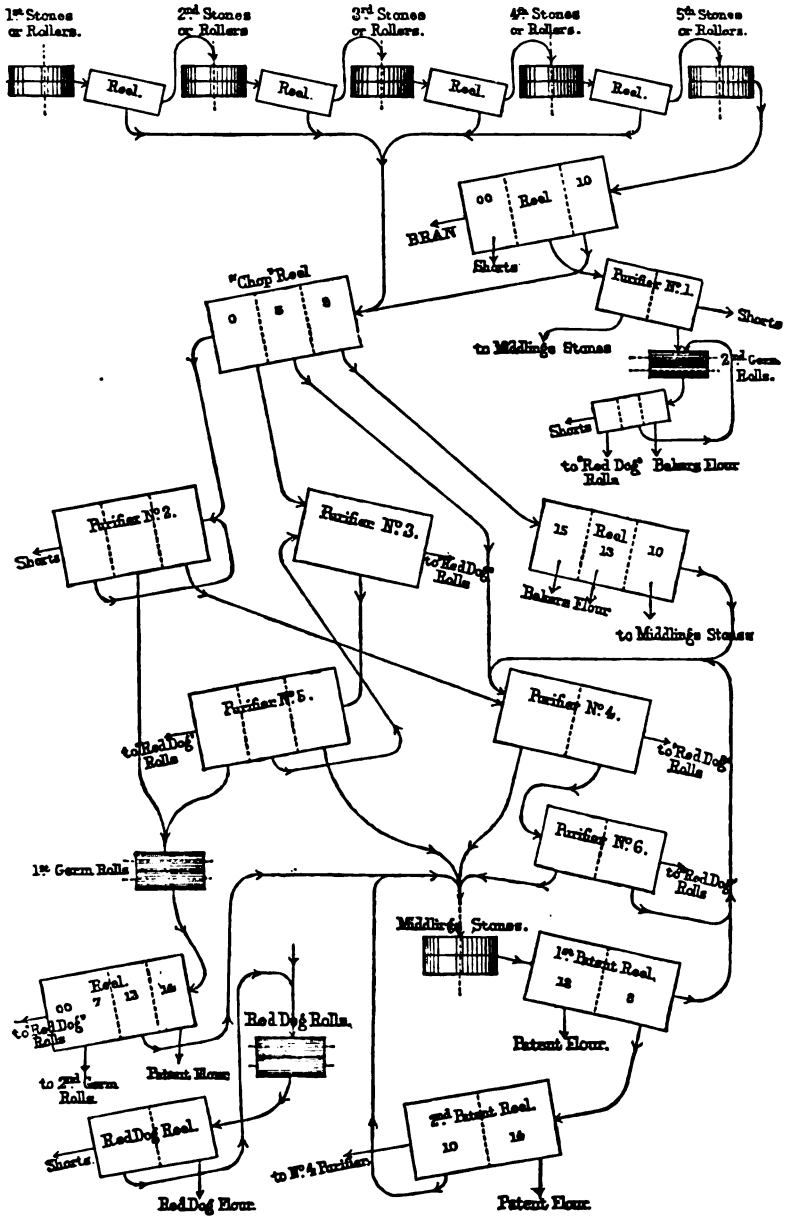


Diagram indicating order of Milling operations.

Digitized by Google

bran. From this break the material passes to a reel covered with bolting cloth, varying in fineness from No. 10 at the head to No. 00 at the tail. What goes over the tail of this reel is sent to the bran bin, and that which goes through next to the tail goes to the shorts bin. The middlings from this reel go to purifier No. 1, or bran middlings purifier, and the flour from this reel is sent to the "chop reel," covered at the head with, say, No. 9, with about No. 5 in the middle, and No. 0 at the tail. To this chop-reel also go the flour and middlings, or "chop," as they are now called, which were taken out between the breaks by the scalping reels. The coarse middlings which go over the tail of the chop-reel go to a middlings purifier, designated purifier No. 2. Those which go through the No. 0 cloth go to purifier No. 3; those which go through No. 5 cloth go to purifier No. 4; while all that goes through the No. 9 cloth, at the head of the reel, is dropped to a second reel clothed with Nos. 13 to 15 cloth, with 2 feet of No. 10 at the tail. The flour from this latter reel goes to the bakers' flour packer; that which drops through the No. 10 is sent to the middlings stones, while that which goes over the tail goes to purifier No. 4. All the intermediate products of the first five breaks are thus successively traced to the bran and shorts bins, to the bakers' flour packer, and to the middlings purifiers, a very small portion going to the middlings stones without going through the purifiers.

The middlings are handled as follows in the purifiers:—From the No. 1 machine, which takes the middlings from the fifth break, the tailings go to the shorts bin, the middlings, which are sufficiently well purified, go to the middlings stones, while those from near the tail, which contain a little germ and bran specks, go to the second germ rolls, a pair of smooth rolls which flatten out the germ and crush the middlings, loosening adhering particles from the bran specks. From the second germ rolls the material goes to a reel, which separates it into bakers' grade flour, fine middlings, which are returned to the second germ rolls at once, some still coarser, which go to a pair of finely corrugated iron rolls for red dog, and what goes over the tail goes to the shorts bin.

The No. 2 purifier takes the coarse middlings from the tail of the chop-reel as already stated. The tailings from this machine go to the shorts bin; some few middlings from next the tail are returned to the head of the same machine, while the remainder are sent to the first germ rolls. The reason for returning is to enable the miller to keep a regular feed.

The No. 3 purifier takes the middlings from the 0 cloth on the chop-reel. From No. 3 they drop to No. 5. A small portion that are not sufficiently purified in No. 5 are returned to No. 3, while those from the head, which are well purified, are sent to the middlings stones; the remainder, which contain a great deal of the germ, are taken to the first germ rolls, which lightly flatten the germ without making more flour than necessary.

The No. 4 purifier takes the middlings from No. 2, and also from No. 5 cloth on the chop-reel, and from No. 10 of the bakers' reel.

Digitized by Google

The middlings from the head of No. 4 go to the middlings stones, and the remainder to purifier No. 6. The tailings from Nos. 3, 4, 5, and 6 go to the red-dog rolls. A small portion not sufficiently purified are returned from No. 6 to No. 4, while the cleaned middlings go to the middlings stones.

The portions which have not been traced either to the bakers' flour or the bran and shorts bins, are the middlings which have gone to the middlings stones, the germy middlings which have gone to the first germ rolls, and the tailings from purifiers 3, 4, 5, and 6, and some little stuff not quite poor enough for shorts, from the reel following the second germ rolls. Taking these seriatim, the middlings, after passing through the middlings stones, go to the first patent reel, covered with 11 feet of No. 13 and 4 feet of No. 8. The flour from the head of the reel goes to the patent packer; that from the remainder of the reel is dropped to another reel, while the tailings go to the No. 4 purifier. The lower patent reel is clothed with No. 14 and 2 feet of No. 10 cloth; from the head of the reel the flour goes to the patent packer, the remainder that passes through the No. 10 cloth, which will not do to go into the patent, being returned to the middling stones, while the tailings are sent to No. 4 purifier.

The germ middlings, after being slightly crushed as before stated, are sent to a reel covered with 5 feet of No. 13 cloth, 5 feet of No. 14, and the balance with cloth varying in coarseness from No. 7 to No. 00. The flour from this reel goes into the patent, the tailings to the red-dog rolls; the middlings from next the tail, which still contain some germ, to the second germ rolls, while the middlings which are freed from germ go to the middlings stones.

The tailings from purifiers 3, 4, 5, and 6, the material from the reel following the second germ rolls, which is too good for shorts, but not good enough to be returned into middlings again, and the tailings from the reel following the first germ rolls, are sent to the finely corrugated red-dog rolls. Following these rolls is the red-dog reel. The flour goes to the red-dog bin, the tailings to the shorts bin, while some stuff, not fine enough for the flour, but too good for shorts, is returned to the red-dog rolls.

This finishes the programme, and although there are probably no two engineers who would agree as to all the details, the main ideas are the same. The system has been well described as one of gradual and continued purification. In a larger mill the various separations would probably be handled a little differently, the flour and middlings from the first and fifth breaks being treated together, and those from the second, third, and fourth also together, the reason being that the flour from the first break contains a great deal of crease dirt, and the fifth more bran dust than that from the other breaks, the result being a lower grade of flour.

The mill for which this programme was made, including the building, cost about £15,000, and is designed to make 60 per cent. patent, 35 per cent. bakers, and 5 per cent. low grade.

In the latter part of the Paper the Author gives another pro-

Digitized by Google

gramme, especially designed for a small mill of about ninety barrels maximum capacity per twenty-four hours. In this case the system is a modification of the gradual reduction system; the five breaks are made with rollers of constantly increasing fineness, and the middlings are worked up on millstones.

Regarding the difference between spring and winter wheat for gradual reduction, it may be stated that spring wheat has a thinner and more tender bran; makes more middlings, because it is harder, and for the same reason the flour is more inclined to be coarse and granular. In milling with winter wheat, especially the better varieties, there will be more break flour made, the middlings will be finer, with fewer bran-specks, and the bran more easily cleaned, because it will stand harsher treatment. Winter wheat requires more careful handling in making the breaks, not because of the bran, but to avoid breaking down the middlings, and making too much and too fine and soft break flour. In order to keep the flour sharp and granular, coarser cloths are used in bolting, and because the middlings are finer, the bolting is not so free, and a larger bolting surface is required. In milling either spring or winter wheat there should be ample purifying capacity, it being very unwise to limit the number of machines. The day has gone by when one purifier would take care of all the middlings in the mill.

A debatable question of the modern systems is the use of millstones. After carefully considering the matter, the Author has come to the conclusion that they have an important place in the new system, that of reducing the finer purified middlings to flour. If the interior of the grain were a mass of flour, needing only to be broken to the requisite fineness, it could be done as well on rolls. But instead of this, the flour part is made up of cells, whose walls are cellular tissue, different from the bran in that it is soft and white, instead of hard and dark coloured. It is also fibrous, and when the fine middlings are passed between rolls, instead of breaking down and becoming finer, it has a tendency to cake and flatten out, rendering the flour soft and flaky. It does not hurt the colour, but it does hurt the strength. When the millstone is used, the flour is of equally good colour, and more round and granular. The advocates of smooth rollers will differ from these conclusions, but the Author believes that the final outcome will be the use of millstones on the finer middlings, and in fact on all middlings that are thoroughly freed from germ.

W. P.

Digitized by Google

The Propagation of Magnetic Waves in Soft Iron.

By HAROLD WHITING.

(Proceedings of the American Academy of Arts and Sciences, vol. xvi., 1881, p. 322.)

The Author describes some experiments on a long ½-inch bar-magnet, begun in 1876 in the laboratory of Harvard University, under Professor Trowbridge, but which, yielding unsatisfactory results (owing it is believed to the mode of measurement adopted), were abandoned. The experiments were resumed, with improved apparatus, in the autumn of 1880, and gave results from which the Author draws the following conclusions :—

I. The magnetic waves induced in a bar of soft iron by an alternating current differ in form, phase and magnitude from the values assigned to them by any theory of instantaneous propagation.

II. They differ in form, inasmuch as the rise and fall of the magnetic wave is in no case abrupt; but it presents, even for a moderate number of reversals to the second, a perfectly rounded crest and trough, especially at considerable distances from the primary.

III. The magnitude of the wave is constant up to five or six reversals per second, after which it is much lessened; from twenty to thirty revolutions it diminishes nearly with the number of reversals (the deflections of the galvanometer remaining constant). From fifty to one hundred and fifty it falls off more and more rapidly, especially for moderate distances along the bar, being there reduced so as to give one-thirtieth of its former deflection.

IV. The phase within the primary is retarded more and more as the rapidity of alternation of the current increases—to a maximum of 90°, and for a distance not too remote is invariably later than it is within the primary.

V. The apparent retardation of the phase depends upon the period (length) of the wave; the arbitrary distance from the primary; the material dimensions and special condition of the bar; and even, in extreme cases, upon the strength and distribution of the magnetic field.

VI. The retardation increases for a certain distance (about thirty diameters) to a maximum of from 127° to 130°; or from 37° to 40° later than that of the primary, falling again, gradually, at great distances, to 90°; that is, to the original value within the primary itself.

VII. The apparent velocity of propagation accordingly increases from a moderate value, in parts of the bar not too remote, to infinity somewhere in its central portion, and then descends, with change of sign, for a still farther advance in distance, to a minimum, and finally becomes infinite again; so that, the most distant portions of the wave reaching their maximum height simultaneously with the nearest, the wave appears to flow backward over the most distant part of the bar.

Digitized by Google

VIII. The apparent velocity of propagation over the first fourteen diameters is from 25 feet per second, corresponding to four reversals per second up to 90 feet for twenty-three reversals, after which it rises nearly in proportion to the number of reversals, until, for one hundred and forty reversals, it measured about 300 feet per second.

IX. The magnetic conductivity of the bar increased (in one case from two to threefold) under the continued influence of the alternating current sent by a high electromotive force, whose use in these determinations must generally be avoided.

X. The retardation of phase is less for small rods than for large ones, but in most respects the effects are similar for distances proportional to the relative diameters of the bars.

XI. The retardation is less for steel than for iron. With steel, a high electromotive force may be advantageously employed to overcome the tendency of the magnetic displacements to become permanent.

XII. The phase of the magnetic wave may be treated as the resultant of that two sets of waves, one due to the direct (and instantaneous) action of the primary itself, and proportional, accordingly, to the time and to the inverse cube of the distance; the other depending upon the secondary effect of magnetism already induced in the bar, and hence proportional, more or less to the square or higher powers of the time, and to the distance as the exponent of a constant factor, less than unity. In the same way that each law of magnetic induction has a parallel in the conduction of electricity, it is probable that the law of change in the one is similar to the law of change in the other.

A Comparative Study of Different qualities of Steel, as regards Magnetism and its permanency. By Raoul Pictet.

(Archives des Sciences Physiques et Naturelles, vol. vi., 1881, p. 113.)

Seven qualities of steel were employed, distinguished by the quantity of carbon; of these seven magnets were made as nearly alike as possible. They were all similarly tempered. Each magnet consisted of three limbs; each of these was separately magnetised by an electro magnet, whose perfect uniformity of strength was measured by means of a galvanometer.

The conclusions to which the Author arrives as the results of his experiments are as follows, the best steel for the purpose under consideration being that which best attains and preserves the highest magnetic power.

English steels containing little carbon were found to answer this description well; but the best magnet was formed from a poor quality of German steel, intended for springs and not tempering

Digitized by Google

well. It was not homogeneous, but composed of an intimate mixture of iron and cement steel, with a low proportion of carbon. This leads to the inference that the magnetic power of magnets depends on the presence of the carbon in the iron, and especially on its aggregation. Too little or too much carbon is bad; about 0·875 per cent. gives the best results. An increase of magnetic power due simply to the contact of its armature is certain for some, but not constant for all qualities of steel. The first magnetic passes seem to develop all the magnetism in artificial magnets.

E. F. B.

Note on a New Method of Printing Barometer- and other Curves.

By H. C. Russell, B.A., Government Astronomer of N.S.W.

(Journal of the Royal Society of New South Wales, 1881, p. 43.)

The necessity for a convenient and expeditious method of printing barometer-curves has induced the Author to devise the following plan. The blanks for the curves containing lines at 29·4, 29·6, 29·8, 30·0, 30·2, and 30·4, and these crossed by vertical lines giving a column to each station, are cast (presumably of type metal) ready for use. So soon as the barometers are reduced, the height at each station is marked in the column for that station, and a pen line is run through these points. The blank is then put under a fret-saw, which is run along the marked curve, and into the saw-cut is placed a ribbon of soft metal, the edge of which serves as a printing surface. This process gives a block which can be printed with ordinary type, and has therefore a great advantage over the lithograph system, in which the curve has to be printed after the map is otherwise complete. An important saving of time ensues, for as soon as the readings are reduced the printing block may be completed in from eight to ten minutes, and at once put in the press. The blanks, which are only $\frac{1}{8}$ inch thick, can be melted as often as required. In the lithograph method a new surface has to be made on the stone each day, and much time is lost in getting the printing adjusted on the prepared map, and then it is not applicable for the daily press. A diagram is appended to this Paper showing specimen barometric curves for six successive days, printed from these blocks, which may be placed together as ordinary types. The process is applicable for printing isobaric, isothermal and other lines.

F. G. D.

Digitized by Google

Units Adopted by the Congress of Electricians (*Paris*, 1881).

(Comptes rendus de l'Académie des Sciences, vol. xciii., pp. 523–5.)

The Committee on Electrical Units of the British Association limited itself to a choice of a system of units based on the determination of physical forces in absolute units related to the metric system. The fundamental units are the centimetre, the mass of a gram, and the second of mean time, and the system thus constituted is designated by the symbols CGS. For practical measures, it appears necessary to choose units that do not give numbers too great or too small for the quantities in habitual use, and useful to designate these units by special names. The Congress has decided that the five most important units—of current, electromotive force, resistance, electric capacity, and quantity of electricity—should be designated by the words, *ampère*, *volt*, *ohm*, *farad*, and *coulomb*.

The most important unit from a practical point of view, and from which all the others may be easily deduced, is that of resistance. In Germany there has been generally adopted, as standard, the Siemens unit, defined, as had elsewhere been proposed by Pouillet, to be the resistance of a column of mercury of 1 square millimetre section and 1 metre length. This resistance is equivalent to about $\frac{95}{100}$ of the ohm, as the latter is determined by the British Association. In the discussion it was admitted unanimously that the standard of resistance should be represented by a column of mercury, solid metals presenting in their electric properties variations dependent on the mechanical or physical operations to which they are submitted. A column of mercury, on the contrary, will always have, at the same temperature, a definite resistance. On the other hand, it appeared very important that the unit of resistance should be established on a purely scientific basis, and in relation to the absolute units. After deep discussion, the Congress decided to preserve the definition of the British Association, and to employ mercury as the standard; but it was judged necessary to make new researches to determine the length of a column of mercury at zero that shall be accepted in practice as representing with a sufficient approximation the resistance of an ohm. The resolutions adopted by Congress are the following:—(1) The centimetre-gram-second system. (2) The practical units, the ohm and the volt: the ohm is a resistance equal to 10^9 absolute CGS units; the volt is an electromotive force equal to 10^8 absolute units. (3) The ohm will be represented by a column of mercury of 1 square millimetre section at 0° C. An International Commission will be charged to determine, by new trials, the length of the column. (4) The ampère is the current produced by the electromotive force of a volt in a circuit of which the resistance is one ohm. (5) The coulomb is the quantity of electricity defined by the condition that, with the current of

Digitized by Google

an ampère, the section of the conductor be traversed by a coulomb per second. (6) The farad is the capacity defined by the condition that a coulomb in a condenser, of which the capacity is a farad, establishes between the armatures, a potential-difference of one volt.

P. H.

Action of Cold on the Voltaic Arc. By D. TOMMASI.

(Comptes rendus de l'Académie des Sciences, vol. xciii., pp. 716–717.)

When the voltaic arc plays between two metallic electrodes, for example of copper-tube bent to U-shape and traversed by a rapid current of cold water, its lighting power is considerably weakened, and it is reduced to a luminous point, even with a current from fifty to seventy-five large Bunsen elements. The arc is then very unstable, the least puff of air will extinguish it, and it will not inflame paper at $\frac{1}{8}$ inch to $\frac{1}{6}$ inch distant. The arc becomes a luminous globule vibrating between the electrodes, and resembles a liquid drop in the spheroidal state. The quantity of ozone developed appears to be increased. Notwithstanding the cooling of the electrodes, the arc is coloured slightly green, proving combustion of the copper.

P. H.

Principle of the Conservation of Electricity, or Second Principle of the Theory of Electrical Phenomena. By G. LIPPMANN.

(Journal de Physique, vol. x., 1881, p. 381.)

In any electrical phenomenon the sum of the quantities of free electricities is constant. If in a system consisting of two parts A and B a cycle of operations occurs leaving A in the same electrical state as that in which it was at the beginning, the sum of the quantities of electricity received by A must be zero. If the state of A depends on two variables x and y, then $dm = X\,dx + Y\,dy$, if dm is a small quantity of electricity added to A. And since $\int dm = 0$ for a closed cycle, dm must be a complete differential, and hence

$$\frac{dX}{dy} = \frac{dY}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

This is the equation which expresses the principle of conservation of electricity. The Author applies it to the case of an air-condenser, one of whose plates is at potential o, in the following way.

Digitized by Google

Boltzmann has shown that the capacity of a condenser whose dielectric is air or any other gas, changes proportionately to the pressure of the gas. The x and y in this case become potential and pressure, X being capacity and Y a new coefficient. The increased energy dE of the system when electricity dm is added depends on $x.dm$ and on $p.dv$ where v is the volume of the gas. Now putting

$$dv = a.dx + b.dp \quad . \quad . \quad . \quad . \quad . \quad (4)$$

as dv is an exact differential, and therefore $\frac{da}{dp} = \frac{db}{dx}$. Again dE must be an exact differential also, and expressing all these conditions it is found that $a = -h$, or that the rate of change of volume of the gas per unit increase of potential at constant pressure can be derived from Boltzmann's experiments. In fact, the dilatation of the gas produced by charging the condenser is equal to the product of half the capacity into Boltzmann's coefficient and into the square of the potential. On Maxwell's theory, which has been verified by Boltzmann, this coefficient is the "refractive power" of the gas. The Author, in the same way, applied his equation (a) to the case of a Leyden jar, as M. Duter has shown that the glass dilates when the jar is charged, the dilatation being proportional to the square of the difference of potential of the coatings. He proves that a change in the capacity of the jar ought to be produced by and be proportional to change of pressure. He applies his theory to the electrification produced in crystals by pressure, to pyro-electricity and electro-capillary phenomena. Summing up the results of his principle, he finds that thermo-dynamical reasoning can be applied to electric phenomena if potential, quantity of electricity and electric energy are made the analogues of temperature, entropy and quantity of heat respectively.

J. P.

On the Yield and the Limit of the Operation of the Transmission of Power by Electricity. By M. Maurice Levy.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xciii., 1881, p. 709.)

Let there be two machines, the one a generator and the other a motor, connected by a circuit, of which the total resistance, including the resistance of the machines, is S. Let P_m be the motive power which must be expended per second to drive the first, and E its electromotive force; P_u the useful work developed by the second, and E^1 is electromotive force, which is of opposite sign to E. If C is the current, $P_m = C\,E$ and $P_u = C\,E^1$, and by Ohm's law $E - E^1 = S \cdot C$.

Digitized by Google

From these three equations are obtained :—

$$C = \frac{E - \sqrt{E^2 - 4SP_u}}{2S}$$

$$E^1 = \frac{E + \sqrt{E^2 - 4SP_u}}{2}$$

$$\frac{P_u}{P_m} = \frac{E^1}{E} = \frac{1 + \sqrt{1 - \frac{4SP_u}{E^2}}}{2}.$$

In order that the current may exist—that is, that C may be a real quantity,

$$S < \frac{E^2}{4P_u}, \text{ so that the greatest value of S is } = \frac{E^2}{4P_u}.$$

It increases as the square of the electromotive force of the generating machine; but this force itself cannot increase indefinitely, because, beyond a certain limit, it is impossible to insulate the wires. Let E_0 be this limit; then there will be for the maximum of S, which cannot be exceeded in any machine, $S = \frac{E_0^2}{4P_u}$.

Hence there exists for the resistance S, through which can be transmitted a given amount of useful work, P_u, a limit independent of the power of the motive or electric machines at disposal, and beyond which the electromotive force only produces disruptive discharges, and not the motion of the motor, just as in the tractive force of a locomotive there is a limit which depends not on the power, but the weight of the machine, when the steam-power produces a slipping of the wheels in place of forward motion.

Given an electromotive force E, equal to or less than E_0, two problems present themselves :—

1. Two dynamo-electric machines having to transmit a useful work, P_u, through a certain external resistance R, with electromotive force E, it is required to determine the velocity to be given to the armature of the generating machine, the necessary consequent velocity of the motor, the electromotive force of the latter, the current and efficiency.

2. Having the same two machines, the same quantity of copper wire wound on the inductors and armatures, the corresponding quantity of insulating material, it is required to modify the sections and lengths of the wires, and consequently their resistances, so as to obtain a better result, and to arrive at the maximum efficiency of which the two given machines are susceptible.

Let b_0 and a_0 be the resistances of the inducing bobbins and of the armature of the generating machine; let n_0 be the number of

Digitized by Google

revolutions of its armature per minute. There exists between the electromotive force E and the current C, a relation of the form,

$$E = \phi(C) \times n_0 \sqrt{a_0 b_0},$$

where ϕ (C) is a function easy to determine experimentally, and to represent graphically, as M. Marcel Deprez has shown. This function, which evidently disappears when C = o, can be reduced to the linear form K C for low values of C, as is the case when currents of high tension, and consequently of small quantity, are taken; the constant R can then be determined by means of a single observation. What is important to note is that, whatever is the form of the function, it continually increases with C; that it is independent of the velocity of the armature; also independent of the resistances a_0 and b_0, if modifying these resistances, care is taken to maintain the quantity of wire and of its insulating material.

There is obtained in the same way for the receiving machine, by accenting the constants, an equation of the form—

$$E^1 = \psi(c) \times n^1_0 \sqrt{a^1_0 b^1_0}$$

in which, for low values of C, $\psi(c)$ can be reduced to the form $K^1 C$.

The total resistance is—

$$S = a_0 + b_0 + a^1_0 + b^1_0 + R.$$

By means of this value of S, there can be obtained from the previous equations C, E', $\frac{P_e}{P_m}$, and n_0 and n'_0.

If, instead of E, n_0 were given in the first place, the problem could equally be solved. The efficiency would be greater, as R was less; that is, as the section of the external circuit was greater, so that to improve the efficiency there must be a sacrifice made on the expenditure at first establishment of the circuit. The resistance R, besides, has a maximum below which it must be kept, and which is—

$$\frac{E^2}{4 P_e} - a_0 - b_0 - a^1_0 - b^1_0.$$

E. F. B.

The Measurement of Energy given to Electrical Apparatus.

By A. Potier.

(Journal de Physique, 1881, vol. x., p. 445.)

In any circuit whatsoever containing machines or lamps, or electrolytes, in which there is a periodic current of variable intensity, *i*, if there be three points at potentials V, V_1, and V_2,

Digitized by Google

and it is wished to measure the electrical energy imparted to the circuit between V_1 and V_2, the method of M. Joubert,[1] gives the mean value of the square of the difference of potential between V and V_2. If there is a resistance R (there must be no self-induction in R), between V and V_1, it is easy to show that what M. Joubert measured is

$$\int (V_1 - V_2)^2 \, dt + 2R \int i (V_1 - V_2) \, dt + R^2 \int i^2 \, dt.$$

Making three experiments with the electrometer, keeping i constant and giving to R three values, the value of each of the above integrals can be found, the second being the mean energy imparted to the circuit between V_1 and V_2.

Another method is this:—Put the Thomson electrometer needle to V_2, and the quadrants to V and V_1, and measure the mean value of $\left(V_1 - V\right)\left(V_2 - \frac{V_1 + V}{2}\right)$.

Now put the needle and a pair of quadrants to V_1, the other pair of quadrants to V, and measure the mean value of half the square of $V_1 - V$.

The difference of these measurements is easily shown to be R times the expended energy which it is desired to ascertain.

J. P.

The Efficiency of Electric Motors. By Dr. A. D'Arsonval.

(La Lumière Electrique, vol. vi. 1881, p. 249.)

This is the conclusion of seven articles.[2] Motors, although very different in form, may be divided into two principal types. The first type comprises motors in which the current is alternately reversed in the moving bobbin by the effect of the commutator; Deprez's motor is an example. In motors of the second type the current changes neither in direction nor intensity, as in the Gramme machine. In efficiency the first type is inferior to the second, and the Author's experiments fully show that the best generator is the best motor.

P. H.

---

[1] Journal de Physique, vol. ix., p. 287.

[2] *Vide* "Lumière Electrique," 7th, 14th, 21st, 24th Sept., and 8th and 15th Oct., and 19th Nov., 1881.

Digitized by Google

Difference of Potential of the Electric Charges which Cover Two Metals in Contact. By H. PELLAT.

(Annales de Chimie et de Physique, 5th series, vol. xxiv., 1881, pp. 5–136.)

This is a long Paper, which takes up the history of the subject, showing that Volta's ideas were weakly attacked by De la Rive, and ably defended by Pfaff; and that all later measurements by Hankel, Gerland, Clifton, and Ayrton and Perry, justify them; whereas their opponents, Brown and Exner, have not justified their objections by their experiments. The Author now proceeds to describe his own compensation method of measurement. He used a Latimer Clark's cell as his standard, as this has been adopted as the standard of the British Association, and fixed by the Association at 1·457 volt; and he has found by comparison of many elements furnished by the Association that it is much more constant than the Daniell. His method is to connect the two plates whose contact difference of potential is to be measured, not by a mere wire, but by a wire in which a battery maintains a certain electromotive force. This is measured by a Lippmann's electrometer, and the electromotive force is obtained by the well-known sliding contact and subdivision of the external resistance of a circuit, including two Daniell's cells. When, after such connection and disconnection of two plates, they are separated from one another, as in the ordinary Volta experiment, and are found, by means of a delicate electroscope, to possess no charges, their contact difference of potential must have been equal and opposite to the electromotive force which was maintained between them by the battery. He has constructed apparatus by means of which his experiments may be conducted in an atmosphere of any kind of gas. He finds that physical and chemical modifications of the surfaces of metal plates influence the measured differences of potential. Thus plates of brass and zinc, cleaned with emery and coated with alcohol, had 0·667 of a Daniell at first, and 0·542 D as their difference of potential four days afterwards. Sir William Thomson and others have noticed the effect of oxidation of the surfaces. The Author finds a marked effect produced by short exposure of copper to sulphuretted hydrogen, a coating notably thinner than the length of a wave of light producing much the same effect as a thick coating. Again, modifications of the surface regarded as purely physical, produce analogous alternations in the measurements, cleaning by rubbing in every case making a metal more positive; the effect disappearing in a few minutes if the rubbing has been by linen or paper, but remaining for a longer time if the rubbing has been more violent; in the case of cleaning by means of emery paper, the effect remains for days. The polish of the surface seems of no account. A notable alteration is found in the potential difference when temperature is altered. The nature, and, above all, the pressure of the gas, which forms the atmosphere about the plate, has a marked

Digitized by Google

effect, although small compared with the total amount of potential difference. For copper and zinc, in every gas examined, the potential difference increases when the pressure diminishes—the effect lagging behind the cause. The Author now proceeds to make a comparison of the electromotive force of a liquid cell with his measured potential differences of the two metals, and finds it to be the same when the liquid is alcohol. He shows that there is every reason to believe in a true large potential difference between the metals themselves; and that the Peltier effect cannot serve to indicate what this ought to be. He also shows that it has a relation, which is only of a vague and remote kind, with the difference of oxidability of the metals.

J. P.

On the Absolute Measurement of Currents by Electrolysis.

By M. MASCART.

(Comptes rendus de l'Académie des Sciences, vol. xciii., 1881, pp. 50–53.)

After discussing the accuracy with which measurement of current quantity can be made by electrolysing a silver salt, found experimentally to be within the limits of less than a one-thousandth, the Author makes this statement as a result of his measurements. That if B. A. units be adopted, a current of 1 weber decomposes in one second 0·09373 milligram of water, or more generally, 0·010415 of an equivalent of a substance expressed in milligrams. The quantity of current capable of producing in one second the electrolysis of one equivalent of a substance expressed in milligrams is 96·01 webers.

P. H.

Chains of Tubes forming Electric Condensers.

By Dr. ANIAN JEDLIK.

(Carl's Repertorium, vol. xviii., 1881, pp. 33–45.)

The Author has invented, and gives some drawings of the way in which he uses, a new kind of condenser of very great electrical capacity in comparison with its size. Glass tubes from 10 to 12 millimetres in diameter, 66 centimetres long, like barometer tubes, equal in length, are filled for more than half their length with iron filings, and their outer surfaces are covered for the same distance with tin-foil, so that each is a Leyden jar. Their inner and outer coatings are all properly united, and the tubes are packed together in a cylindrical glass jar, each end of which is

Digitized by Google

covered with a hollow brass ball, which is connected with one or other of the two sets of coatings. A number of these jars may, of course, be taken together when considerable capacity is wanted.

J. P.

Duration of Induced Currents. By Raimond Coulon.

(La Lumière Électrique, vol. vi., 1881, p. 198.)

In a series of ten elaborate articles,[1] the Author considers the subject bearing this title. The following are the practical deductions.

Alternating and continuous current machines have a limit of velocity, beyond which the currents produced are more or less neutralised. In alternating machines this limit may in practice be attained and passed, which is never the case with continuous machines. In alternating machines the greatest amount of electricity is obtained when the preceding current ceases at the moment the succeeding current is created. In continuous machines this amount corresponds to a variable of each machine. With alternating current machines, it is of advantage to diminish the velocity and increase the mass, especially when they are intended to give currents of tension. Continuous current machines should be light, and have high velocity; it is better to obtain tension by increase of velocity than by reduced diameter and increased length of wire. The Author believes the best results would be attained by small machines run at a speed of three thousand to four thousand revolutions a minute.

P. H.

On Dynamo-Machines. By Dr. O. Frölich.

(Elektrotechnische Zeitschrift, 1881, pp. 134–170.)

This a résumé of a long series of experiments with dynamo-machines of Siemens and Halske's make. The Author sets out with the formula expressing the quantity of current furnished by a magneto-electric machine; which is

$$I = \frac{n M \nu}{R},$$

where I is the quantity of current, ν the number of revolutions made by the armature in a minute, n the number of convolutions of the armature-coil, R the total resistance of the circuit, and M a

[1] "La Lumière Électrique," July 1st, Aug. 15th, and 16th Oct. 1880. *Ibid.* Jan. 15th and 22nd, March 5th and 12th, and Aug. 6th and 13th, 1881.

Digitized by Google

quantity that may be defined as the ratio of the electromotive force to the number of revolutions, and this the Author terms the "effective magnetism." It is the sum of the electromotive forces that the permanent magnets and the iron of the armature develop in a convolution of the armature when the number of revolutions = 1.

In a dynamo-electric machine in which the inductors are magnetised by the current developed:

$$M = f(I),$$

and the preceding equation may be written under the form

$$\frac{I}{n\,M} = \frac{I}{f(I)} = \frac{\nu}{R}.$$

Accordingly the quantity of current is merely a function of the ratio $\frac{\nu}{R}$ between the number of turns per minute and the total resistance; and this conclusion applies to all dynamo-electric machines whatever may be the position of the collectors. The earlier experiments were to verify the relation between the quantity of the current and the ratio $\frac{\nu}{R}$. A large Siemens machine was used, with three successive different windings:

Windings.	Inductors.			Armature.		Total Resistance of Machine S.U.
	Mean Distance between the Wire and the Convolutions.	Number of Convolutions.	Resistance S.U.	Number of Convolutions.	Resistance S.U.	
	Millimetres.					
I.	10·5	456	0·290	288	0·145	0·435
II.	21·0	856	0·580	288	0·145	0·725
III.	14·0	1,960	4·14	1,296	3·000	7·140

In this Table the resistances are expressed in Siemens' units, consequently the quantities will be expressed in $\frac{\text{Daniell's cells}}{\text{S.U.}}$, defining a Daniell cell with Kohlrausch as having the electromotive force that, on a resistance of one Siemens' unit, will produce a current capable of depositing 1·38 gram of copper an hour.

In the experiments the position of the brushes was always so chosen as to give maximum current.

Tables I., II., and III. contain the results obtained with Windings I., II., and III.

Digitized by Google

TABLE I.—WINDING I.

ν Number of Turns.	R Total Resistance.	I Quantity.	$\frac{\nu}{R}$	$M = \frac{I R}{n \nu}$
112	2·77	0·30	40·4	0·000026
203	2·78	0·58	73·0	0·000028
301	2·79	7·18	108·0	0·000233
400	2·81	19·90	143·0	0·000486
390	2·83	19·90	138·0	0·000500
510	2·70	32·00	189·0	0·000587
610	2·69	40·20	227·0	0·000615
709	2·74	44·70	259·0	0·000601
812	2·80	50·40	290·0	0·000604
919	2·71	55·70	339·0	0·000569
114	0·92	6·90	124·0	0·000194
207	0·94	39·50	220·0	0·000622
313	0·97	58·40	323·0	0·000629
415	1·01	71·10	411·0	0·000601
497	1·02	79·80	487·0	0·000569
		TABLE II.—WINDING II.		
201	3·10	10·40	64·8	0·000556
415	3·14	24·00	132·0	0·000646
609	3·24	33·90	188·0	0·000625
812	3·31	46·40	245·0	0·000656
206	2·12	18·40	97·2	0·000656
408	2·12	40·90	192·0	0·000736
607	2·08	62·90	292·0	0·000750
195	1·27	32·10	154·0	0·000726
399	1·29	67·70	309·0	0·000760
207	3·24	10·40	63·9	0·000566
		TABLE III.—WINDING III.		
202	19·00	7·95	10·60	0·000577
304	19·20	12·60	15·90	0·000612
199	22·70	5·95	8·77	0·000524
301	23·00	10·20	13·11	0·000001
405	23·30	13·60	17·40	0·000604

These results are represented by curves.

The quantities of current with the Windings I. and II. are comprised between 20 and 50 $\frac{\text{Dan.}}{\text{S.U.}}$, and as within this limit the curves are nearly a right-line, it is practically admissible to say that the quantity of current is a linear function of the ratio $\frac{\nu}{R}$. This is not so with a magneto-electric machine exactly, as this kind of machine gives a current for small values of ν.

Properly selected ratios of these figures will show that the effective magnetism increases proportionately with the quantity of current to a magnetic maximum of the inductors.

According to Joule's law the work absorbed per second by the machine is $T = c\ I^2$, $R = c\ I\ E$, where, as by Kohlrausch,

Digitized by Google

$c = 0{\cdot}00181$ when the work is expressed in HP., the electromotive force in Daniell's cells, and the resistances in Siemens' units. But the Author introduces a correction for currents induced in the iron of the armature, and the expression becomes $T = c\,I\,E + p\,E^2$. Experiments on the transmission of power show that, in the present case, $p = 0{\cdot}0009$, so that c becomes $c' = 0{\cdot}00163$.

The Author has studied the transmission of power to a distance by passing the current from a machine (of Winding I.), designated the primary machine, into a similar machine, which becomes the motor, and is termed the secondary machine. If the commutator is at the same angle in the two machines, the quantity of current, and consequently the effective magnetism, may be assumed the same in both machines. If, then, E be the electromotive force, I the quantity, R the total resistance, M the active magnetism, ν the number of revolutions, n the number of convolutions of the armature, T the work, S the heat disengaged, and N the efficiency, and if the index 1 indicate the primary, and 2 the secondary machine, the following relations occur:—

$$E_1 = \nu\,M\,\nu_1;\ E_2 = n\,M\,\nu_2;\ I = \frac{E_1 - E_2}{R};$$

$$T_1 = c\,E_1\,I = c\,I\,R\,\frac{\nu_1}{\nu_1 - \nu_2};\ T_2 = c\,E_2\,I = c\,I^2\,R\,\frac{\nu_2}{\nu_1 - \nu_2};$$

$$S = c\,I^2\,R;\ T_1 = S + T_2;\ N = \frac{T_2}{T_1} = \frac{\nu_2}{\nu} = \frac{E_2}{E}.$$

Experiments show, however, that these results are not completely confirmed. The efficiency that according to these equations should in certain experiments attain 90 per cent. does not attain 60 per cent., and for a constant value of ν, there occurs always a maximum efficiency for a certain value of ν_2, which does not accord with the formulæ. The cause of the anomalies the Author attributes to the currents produced in the iron of the machine. In the primary machine these currents are in the same direction as those in the armature wire; they enfeeble and diminish the effective magnetism and the electromotive force, at the same time increasing the work expended. In the secondary machine, which revolves in a contrary direction, these currents are opposite to those in the wire; they increase the effective magnetism and diminish the work produced.

Supposing the commutator to have the same rake in the two machines, and representing by i_1 and i_2 the currents induced in the iron of the armatures; by r the resistance of the circuit traversed by these currents; by e, a coefficient dependent upon the machine; and by M_1 and M_2 the effective magnetism,

$$M_2 = M + e\,i_2;\ M_1 = M - e\,i_1;$$

$$i_2 = \frac{M_1\,\nu_1}{r} = \frac{1}{n}\,\frac{E_1}{r};\ i_2 = \frac{M_2\,\nu_2}{r} = \frac{1}{n}\,\frac{E_2}{r}.$$

Digitized by Google

If $\frac{e}{r}$ be put $= \eta$,

$$M_1 = M(1 - \eta \nu_1); \text{ \&c.}$$

The Author deduces

$$T_1 = c I E_1 + p E_1^2; \; T_2 = c I E_2 - p E_2^2$$

$$N = \frac{T_2}{T_1} = \frac{E_2}{E_1}\left[1 - \frac{p}{c I}(E_1 + E_2)\right]$$

$$S = c I (E_1 - E_2); \text{ where}$$

$$\frac{c}{n^2 r} = p.$$

If F_1 and F_2 be the work corresponding to the induced currents in the iron of the armatures

$$F_1 = p E_1^2 \quad F_2 = p E_2^2$$

$$T_1 = T_2 + S + F_1 + F_2.$$

These values are expressed at length as functions of I, R, ν, and ν_2. These formulæ are applicable also to all angles or rakings of the commutator, and to all machines. The constants η and p have been found to be

$$\eta = 0{\cdot}00015 \text{ and } p = \frac{7{\cdot}5}{n^2},$$

whilst c, which is given by Kohlrausch as 0·00181, must be reduced to 0·00163.

P. H.

New Kineto-Electric Machine. By M. Deblanc.

(La Lumière Électrique, vol. iii., pp. 72–75.)

This is an inductive machine, consisting of a series of condensers in the form of sectors of a cylinder, mounted on a shaft and kept in revolution by a pulley, and an inducting body charged from an electrostatic machine; a commutator on the shaft converts the alternating currents into one of single direction. The machine is hypothetical, and does not appear to have been yet constructed.

P. H.

The Various Systems of Electric Light. By E. Hospitalier.

(Journal des Usines à Gaz, October 10, 1881.)

There are electric lamps of varying intensities, from the large arc lights, equal to from 400 to 500 Carcel lamps, down to the small incandescent lamps; so that, apart from the question of cost, electric lighting can be applied to all purposes.

Digitized by Google

A close relation exists between the power and colour of the light; as the power decreases, the light becomes redder. Without precisely fixing the proportion, it may be said that the large arc lights yield a light equal to from 100 to 150 Carcel lamps per HP. The Jablochkoff light about 40 Carcels; Werdermann's lamp 25 to 30 Carcel's; and the incandescent lamps of Edison, Maxim, Swan, &c., 8 to 10 Carcel lamps per HP. As regards the heat developed by the various lights, the large arc lights of 100 Carcels are estimated to develop 6 calories per Carcel per hour, the small arc lights 16 calories, Werdermann's lights 25 calories, and the small incandescent lamps 60 to 80 calories per Carcel per hour; while with coal gas 1,500 calories per Carcel per hour are developed with ordinary burners, 525 calories with the Bengel burner, and 200 calories with Siemens burners. With incandescent lights, therefore, equal in power to the Bengel burners, the heat developed is only one-tenth that of gas; with large arc lights the difference is much greater, and, for equal light, the heat developed is 150 times greater with gas. It is impossible to arrive at general conclusions with regard to the cost of electric lighting compared with gas. In factories, where steam-power is at hand, and it is only necessary to provide a dynamo-electric machine, the advantage would be great, and electricity would also be the cheapest for large spaces. At the Paris Hippodrome it is stated that the lighting by gas formerly cost 1,100 francs per night, while with the present electric lighting it costs only 250 francs. In 1878 the carbons for the Jablochkoff light cost 75 centimes; in 1879, 40 centimes (?); and in 1880, 50 centimes for two hours' burning; during the first six months of 1881 the price was 40 centimes, and it has since been reduced to 30 centimes. Also, the former cost of the machines was 6,000 francs, which is now reduced to 3,000 francs, and it is to be expected that they will become still cheaper. For comparing the two lights it is necessary to establish some unit of measure, which cannot be calculated by volume as with gas, but must be estimated by the work done; the "horse-hour" may be adopted, that is to say, 75 kilogrammetres during three thousand six hundred seconds, or 270,000 kilogrammetres (1,953,166 foot-pounds) per hour.

With a central station, capable of supplying several thousands of HP., electric light could be distributed at a cost of 20 centimes per "horse-hour," including wear and tear and renewals at the central station, and the wires, carbons, wages, &c. This "horse-hour" would supply five to six incandescent lamps, which, compared with the light developed, would correspond to the consumption of a cubic metre (35·316 cubic feet) of gas producing a light equal to 10 Carcel lamps. The "horse-hour" of electrical energy would therefore be equal to a cubic metre of gas, and for 20 centimes with the incandescent electric light an equal illuminating power would be obtained to that costing 30 centimes with gas. At the present price of gas (in Paris) electric light would therefore be the more economical, provided it was gene-

Digitized by Google

rated on a large scale, but at 15 centimes the cubic metre (3*s.* 5*d.* per 1,000 cubic feet) gas would have the advantage.

From this it is concluded that electric light is not a rival of gas, but that they should be worked and distributed together, and that the same works should supply the two lights, the waste heat from the retort benches being utilised for generating electricity, and by making use of the one or the other, as may be most advantageous in each case, a union would be effected, the benefits of which cannot yet be foreseen or defined.

C. G.

L. Scharnweber's Electric Lamp.

(Zeitschrift für Angewandte Elektricitätslehre, vol. iii., 1881, p. 348.)

In the upper part of the frame is a solenoid, wound in three separate divisions with thick insulated copper wire, and in the hollow of this solenoid slides the positive carbon holder, the negative carbon being permanently fixed to the lower part of the frame. Attached to the upper holder inside the solenoid is a rod, consisting of alternate pieces of iron and brass, which is partly supported by a small chain passing over a pulley, and counterbalanced by a weight. A sliding contact piece, attached to the pulley, is pressed by a spring against a ring, divided into three segments, insulated from each other, each segment being in connection with a separate division of the solenoid. The action of the lamp is as follows:—When no current passes, the upper carbon, owing to the preponderance of the core over the counterpoise, makes contact with the lower one; but as soon as the current passes, part of it is shunted through that one of the windings of the solenoid which is in connection with the segment of the three-part ring, which is in contact with the spring, and so with the body of the lamp. The iron core, which is partly within this division of the solenoid, is attracted, and so draws an arc. As the carbons burn away, the iron core descends, and, in so doing, causes the pulley, over which passes the chain, to rotate. This movement brings the contact spring against another segment of the divided ring, and the current is shunted through a different division of the solenoid, which then acts on the second iron core within it, and again draws an arc. The same action brings the third division of the solenoid into work, and then the first over again. There is also an arrangement introduced to equalise the attractive power of the solenoid on the iron core, no matter what position it may occupy inside the former. Three pins project from one side of the pulley, and press successively on a lever having a weight at its farther end. In this way the stronger attractive force of the coil as the core enters it is counterbalanced by the increasing weight of the lever as it is raised into a more horizontal position by the pin pressing on the near end. When the spring makes contact with the second segment of the

Digitized by Google

divided wheel, the first pin releases the lever, and the second pin comes into play.

The Author describes a second form of lamp, in which the solenoid is wound with more turns of a finer wire, and the current from the lower carbon passes through a platinum or German silver wire, which expands, owing to its increase of temperature. This expansion, by means of a system of levers, draws down the lower carbon-holder, till brought up by a metal stud on the metal framework of the lamp, through which the current then passes, and allows the wire to cool again and contract. The arrangement for feeding the upper carbon is the same as in the first form of lamp.

G. P. S.

The Underground Conducting Network of the German Imperial Telegraph System.

(Elektrotechnische Zeitschrift, 1881, pp. 381–3.)

With the completion of the cable line from Cologne to Aachen the Imperial Telegraph network has been finished for the present, according to its large original plan. The whole important work has occupied more than fifty-eight months, and entailed an expenditure of £1,510,000. The network encloses two hundred and twenty-one towns, among which are the most important commercial and fortified towns of the empire. In the Paper a Table is furnished of the dates at which the laying of each section of the net began and ended, and another Table gives the lengths of the principal portions. The whole length of cable is 5,464 kilometres, containing conductors of a total length of 37,372 kilometres. There are seventy pieces of cable crossing rivers, sixty-two of them having seven wires, seven of them four wires, one of them fourteen wires.

J. P.

Application of the Radiophone to Telegraphy. By E. MERCADIER.

(Comptes rendus de l'Académie des Sciences, vol. xciii., 1881, p. 541.)

The Author causes each radiophonic transmitter to induce vibrations in the electric circuit corresponding to a definite musical tone, and by intermitting the rays of light falling on the perforated revolving disk, by a disk attached to a Morse key, obtains in each receiving telephone Morse signals in musical tones. By instructing each operator to distinguish only those signals corresponding to a given tone, it is found possible to transmit numerous messages in either direction at one and the same time. The selenium cells of the radiophones and the telephones are all included in a single direct circuit.

P. H.

Digitized by Google

On the Manufacture of Magnets. By G. Trouvé.

(Comptes rendus de l'Académie des Sciences, vol. xciii., 1881, pp. 311, 312.)

The Author communicates the method by which he has attained success in the making of permanent magnets. Three points are observed: (1) to obtain the best steel, (2) to determine the degree of temper, (3) to select the most simple and practical process of magnetisation. The tempering is effected in a gas muffle at a constant temperature. The magnetisation results from placing the bars in two juxtaposed solenoids, the magnetic circuit being closed by two plates of soft iron; the current is obtained from a battery of 6 Wollaston elements. Magnets so made will carry twelve to fourteen times their weight; if the magnet is bent to a horse-shoe, the charge is quadrupled, that is to say, the magnet will carry forty-eight to fifty-six times its weight. Magnets furnished with bobbins having 120 metres of No. 36 wire (0·1 millimetre in diameter) and a resistance of 240 ohms make very powerful Bell telephones.

P. H.

On a Case of Permanent Polarity in Steel opposed to that of the Magnetizing Coil. By A. Righi.

(Il Nuovo Cimento, vol. vii., 1881, p. 135.)

As a result of his experiments, based on theoretical considerations, the Author finds that, "If we take cylindric bars of steel of the same diameter, we always find, for the same value of the magnetizing force of the coil, a bar of such length that it cannot acquire any trace of permanent magnetism; so that with shorter bars we may obtain a permanent polarity contrary to that which is developed during the passage of the current in the coil."

J. P.

On the Magnetic "After-Effect."

By Felix Auerbach.

(Wiedemann's Annalen, 1881, p. 308.)

In all the magnetic theories of Poisson and others, the magnetic state of a body at any time is supposed to depend merely on the magnetising forces at this time.

Under "after-effect" are understood two kinds of phenomena. The one, the changing magnetic state of a body during the action of a constant magnetising force, or after the force ceases to act; the other being the dependence of magnetic state not merely on

Digitized by Google

the amount of magnetising force acting at the time, but on the amounts of these forces which acted before this time, and the previous conditions of the body. As to after-effect in elastic phenomena and in magnetism, the Author mentions the work done by Kohlrausch, Fromme, Meyer, Warburg, and himself.

The Author has already considered, in a previous communication, "after-effect" of the second kind. The general question which remains to be answered is, how does the present magnetisation, m, depend on the magnetising forces $J_1 \ldots J_p \ldots J_2$, respectively, which have acted at a previous time when the magnetic conditions were $M_1 \ldots M_p \ldots M_2$, and this he has tried to answer. In the present Paper, as the question is a complicated one, he gives a qualitative answer, reserving for a future communication his numerous tables of experimental results and formulæ. The arrangement of his experiments was the same as in his first researches.[1] The body operated upon was a hollow soft-iron cylinder, $5\frac{1}{2}$ inches long, 0·69 inch in diameter, magnetised by means of a coil of wire. The following are some of his results: If the magnetising force i, following on a condition of no force, would produce the magnetisation m_o; then, if besides the force i acting at present, a series of forces, $J_1 \ldots J_p \ldots J_2 \ldots$ acted previously, instead of the magnetisation m_o, there would now be the very different magnetisation m, the difference between them being the "after-effect" of the previous forces. J_1 is of importance in maintaining after-effect, so long as all the succeeding values of J lie between J_1 and i, but after any subsequent value of J lies outside these limits, it may be considered that no after-effect is due to J_1. Again, of two previous forces which lie upon different sides of i, the second alone is of importance if it lies farther than the first from i; in every other case they are both of importance in determining the value of m; it is never the case that the first alone is useful. Permanent magnetisation of steel is a special case of "after-effect," and its laws are merely special cases of general laws. Just as it was found that, when forces followed one another discontinuously, certain intermediate forces are of no consequence, so it is found that, if the force alters continuously, the rate of change is without influence on the after-effect—at least, the influence is small in comparison with the after-effect itself. If the magnetic force be increased suddenly, a magnetisation results which decreases in time, at first quickly, then slowly, and approaches a constant value, which is however greater than the constant value produced after very slow production of the same force. The rate change of force is only of influence on the "after-effect" of the second kind, when it is so great that it causes an after-effect of the first kind. Lastly: The magnetic after-effect is in no case very small in comparison with the magnetic effect itself, although it is always less, but between a value equal to the effect itself and zero it may have all values. It is not easy for it to approach the value zero. The Author concludes by saying that

[1] Wied. Annalen der Physik und Chemie, No. 11, p. 353, 1880.

Digitized by Google

no theory of the cause of the second kind of after-effect can be worked out till the phenomena of the first kind of after-effect are thoroughly mastered.

J. P.

Magnetic Speed-Meter. By MARCEL DEPREZ.

(Zeitschrift für Angewandte Elektricitätslehre, vol. iii., 1881, p. 401.)

Many instruments have lately been constructed to measure the velocity of rotation of machines, and the Author describes those of Daniell and Schäffer and Budenberg, which depend upon centrifugal force. His own instrument is on the principle of Arago's copper disk, namely, that when a plate rotates in front of a magnet the tangential force is proportional to the angular velocity of the disk, the conductivity of the material, and the intensity of the magnetic field, so that, knowing this force, the velocity of rotation might be calculated. A U-shaped magnet is made to rotate about an axis parallel to its limbs, a pulley being attached to a piece connecting the two poles of the magnet, so that it may be driven by a band from any machine whose speed is required. The magnet turns on a hollow axle, through the centre of which is the pivoting of a hollow cylinder of copper, containing a soft iron core placed between the limbs of the magnet. This copper tends to rotate, and is prevented by means of a counterpoise, and a long pointer shows on a scale how much the counterpoise is deflected from the perpendicular at any speed. It is evident that the angular velocity of the magnet is measured by the sine of the angle of deviation of the pointer from its zero position. The counterpoise is replaced in some instruments by spiral springs.

J. P.

Electrical Thermometers for observing Temperature at a Distance. By MAX LINDNER.

(Zeitschrift für Angewandte Elektricitätslehre, vol. iii., 1881, p. 400.)

In 1877 Herr Eichhorn made experiments with several platinum wires hermetically sealed into the sides of a thermometer, at such distances that a rough graduation was possible by the electrical contacts made by the rising or falling mercury; and in this year he used the instrument in a malt manufactory, with much success, for the regulation of the heating arrangements.

For use in brewing, the firm of Oscar Schöppe, of Leipsic, enclose the thermometer in a wooden case, and they can connect the several wires at will with electro-magnetic bell arrangements, so that a bell rings as soon as the temperature reaches a certain height. The distances to which these wires have to be taken are usually small,

Digitized by Google

and only a few wires are necessary, so that the cable is not of an expensive character. The insulating material of the silk-covered wires of the cable is asphalt. The temperatures of cooling vessels, as well as heating vessels, are controlled by means of these thermometers, which are also employed for opening and closing ventilators, &c. They act very well everywhere, and may be depended upon, and this is in favourable comparison with the bad action of the ordinary thermo-electric thermometers.

J. P.

Use of the Telephone as a Means of Communication during the Training of Infantry in Shooting.

By Lieutenant von LAFFERT, of Bautzen.

(Elektrotechnisches Zeitschrift, 1881, col. 288.)

In order to represent as closely as possible the real circumstances of war, the dummy soldiers, which serve as targets, are made movable, so that they can be raised or lowered at will, and thus imitate the appearance or disappearance of fresh bodies of troops. A means of communication is necessary between the markers moving the dummies and the officer in command of the shooting party, so that the latter may direct the movements without the soldiers knowing in what direction they are to expect the dummy enemy. The heliostat and ordinary telegraph have been tried without fulfilling the various exigencies of the case. The telephone, on the other hand, has proved very suitable as a means of communication. The form of telephone used was that made by Messrs. Siemens and Halske, of Berlin. Two kinds of cable were employed, the first being composed of two copper wires, 0·8 millimetre in diameter, insulated with india-rubber and covered with yarn, laid up into a cord with two strands of yarn, the whole having an outer covering of yarn dipped in wax. This cable answered better than the second kind, which consisted of two 0·9-millimetre copper wires, insulated with india-rubber, and laid side by side; but owing to its flat form, it was very liable to form kinks. The cable was coiled on a cylinder made of tin plate, 0·4 metre long and 0·12 metre in diameter, with ends of hard wood 0·32 metre in diameter screwed to it. The hollow of the cylinder was divided by a diaphragm, so that a telephone could be placed in each end, and a hole was bored in the cylinder to admit one end of the cable, which was connected to one of the telephones. Attached to the wooden ends were two iron eyes, to receive the handles for carrying the drum, and to one of which could be attached a winch for winding up the cable when necessary. The whole drum, with 500 metres of cable coiled on it, and its two telephones inside, could be carried by one man slung to a strap. To lay the cable, two men carried the drum, one on each side, and

Digitized by Google

let the cable pay out as they walked along. The cable was supported by screw clamps attached to a spike, which could be screwed into trees or posts. To be out of reach of stray shots, the cable was led along at some distance from the line of firing, and where it had to cross this line, was laid in a shallow trench. The Paper gives an account of the manner of arranging the several stations, which is chiefly interesting from a military point of view.

G. P. S.

On the Future Technical Training of Smelters.

By Hr. Schlink.

(Stahl and Eisen. Vol. i., p. 86.)

The Author propounds the question: Is a course of study at a technical high school absolutely necessary for machinists and smelters? and answers without qualification in the negative. In support of his views he takes two youths of equal age, with grammar school (Realschule I. Ordnung) training, the first, A, being subjected to a four years' course of training on the mechanical mode of a technical school such as that of Aachen, and afterwards sent as an improver to a machine shop for two years more, when he is supposed to be capable of supporting himself. The total necessary expenditure during the six years is estimated at 6,000 marks, £300.

The second youth, B, under the Author's scheme, is sent directly from school to the works, where he passes through the different departments from the drawing office upwards, and in four years is turned out a finished workman. His school training should be sufficient to allow him to acquire, by further private study, the additional scientific knowledge that he may require in the future practice of his profession. The total expenditure for the four years, after deducting probable earnings, is put at 2,500 marks, £50, or £250 less than that of his school-trained colleague. Afterwards he is recommended to go abroad for two years, *e.g.*, to England, where skilful German draughtsmen are in demand, and return with enlarged knowledge, in addition to having mastered the English language.

The Author next presents a similar contrast between A, trained for four years according to the metallurgical programme of the Aachen School, and requiring two years' practical training in the works before becoming self-supporting, and B, who, following the course recommended by the Author, works for a year or a year and a half in some analytical laboratory, which may either be a private one or that of a university or technical school, and then enters the works for a three years' practical training in all branches of the business, finishing up with two years of foreign experience, as in the preceding case.

Digitized by Google

The Author points out that the course of training he recommends is substantially that followed in England and North America. The complaint often heard in these countries of the want of theoretical knowledge in men so trained is, he considers, to be attributed to the want of preliminary general scientific training in the period of school education, and that when this want has been supplied there will be no desire to make great alterations in the ordinary practice of professional education in the works. He therefore thinks that sooner or later in Germany the courses of study, that are being continually lengthened, will be again shortened, and an earlier introduction to practical training will be preferred.

The Author, in conclusion, while appreciating the value of a complete course of academical training, denies its unconditional necessity, and considers that the modified course he has sketched is preferable, especially in the case of a young man of limited means, who may thereby enter sooner on professional life, without prejudicing his future prospects.

H. B.

Digitized by Google

Digitized by Google

INDEX

TO THE

MINUTES OF PROCEEDINGS.

1881-82—PART I.

Abbey, H., admitted student, 199.
Abel, F. A., C.B., elected honorary member, 200. *Vide* also Noble.
Abernethy, J., Past-President, report by, in 1875, on the river Ouse, referred to, 212, 218.
————, remarks as to the conservancy of rivers, 249.—Ditto as to proximate legislation on the subject, 249, 280.—Ditto as to Vermuyden drainage works in the Fens, 280.—Ditto as to the decay of the early drainage works, 281.—Ditto as to the action of tidal waters, 281.—Ditto as to dredging, 281.—Ditto as to the river Tyne, 282.—Ditto as to the proposal to dam out the flood tide, 282.—Ditto as to the evils of divided jurisdiction in river conservancy, 282.—Ditto as to maintaining the banks of rivers, 282.—Ditto as to the Danube at Vienna, 282.
Abt, R., the rolling stock of the St. Gothard railway, 467.
Adams, W. B., his iron permanent way referred to, 5.
Adamson, J. G., memoir of, 403.
"Adventurers," works of the, in draining the Fens, 203.
Aerial navigation, "A Study of the Problem of Aerial Navigation, as affected by Recent Mechanical Improvements," 369.—The serious discussion of the problem, hitherto impeded by fear of ridicule, 369.—What has been done, 370.—What may be done, 375.—Dirigible balloons, 386.—Practical considerations, 388.—Aerial navigation, 392.—Summary, 393.
Aerostatic machines, account of, devised for aerial navigation, 369, *et seq.*
"After-effect," magnetic, on the, 538.
Air blast, use of, for cleaning coal, 504.
—— condenser, application of the, to steam-ballooning, 383.
Alexandre, N., rolling foot-bridge over the Duquesne lock at Dieppe, 454.
Algerian railways, use of iron sleepers on the, 69, 120.
Allan, G., remarks as to metallic permanent way, 60.—Ditto as to the history of iron sleepers, 60.—Ditto as to the advantages of the pot system over longitudinal or transverse sleepers, 60.—Ditto as to the causes which had hindered the adoption of metallic sleepers in England, 60.—Ditto as to the advantages of steel over wrought or cast iron as a material for sleepers, 61.
Allen, C. H., elected associate member, 200.
Alty, H., elected associate member, 200.
Amberg, Bavaria, iron ore from, 483.

Digitized by Google

American milling methods, 513.
——— stamps for gold and silver ores, 497.
Anderson, W., his formula for the weight of a framed girder, 332.
Andra, R., the sluicing basin at Honfleur, 464.
Andrews, T., elected associate member, 200.
Arc, voltaic, action of cold on the, 523.
Archbould, R., elected associate member, 200.
Arrow, J. T., remarks as to metallic permanent way, 62.—Ditto as to the steel sleepers used on the Oude and Rohilkund Railway, 62.
Artillery, recoil of. *Vide* Gun-carriage.
Artingstall, S. G., elected associate member, 200.
Atkinson, W., remarks as to the conservancy of rivers, 278.—Ditto as to floods in the Irwell, 278.—Ditto as to the proposed tunnel to carry off the flood water from above Salford, 278.—Ditto as to legislation on rivers, 279.—Ditto as to the evils of the multiplicity of authorities in the Fen districts, 279.—Ditto as to the means of levying rates for river improvement, 279.—Ditto as to the inadequacy of the Government Bill, 279.
Auerbach, F., on the magnetic "after-effect," 538.
Austria, conservancy of rivers in, 269, 305.
Axles, steel for, 353.

Bass, J. R., admitted student, 199.
Bacup, source of the Irwell at, 234.—Rainfall at, 236.
Baker, B., his formula for the weight of a framed girder, 333.—"Steel for Tires and Axles," 353.
———, C. J. S., elected associate member, 200.
———, J. B., elected associate member, 200.
Ballast, the most suitable for use with metallic permanent way, 21.
Balloons. *Vide* Aerial Navigation.
Barlow, W. H., Past-President, his system of iron longitudinal permanent way referred to, 3 *et seq.*
———————, remarks as to the elastic field gun-carriage, 162.—Ditto as to the possible strain on the trunnions of a gun, 162.—Ditto as to the mathematics enunciated in the discussion on Mr. Butter's Paper, 162.
Barometer curves. *Vide* Curves.
Barry, J. W., remarks as to the conservancy of rivers, 258.—Ditto as to the circumstances of the river Hull, 258.
Bars (river), formation of, 271.
—— (metallic) loaded, self-recording indicator of the elastic extension of, 428.
Barton, J., his evidence in the Banu Reservoir inquiry referred to, 321.
Base lines, apparatus for measurement of, 421.
Bashforth, F., remarks on the elastic field gun-carriage, 172.—Ditto as to the action of exploding gunpowder in the bore of the gun, 172.
Basiaux and Léonard, Messrs., cleaning coal by an air blast, 504.
Basin, sluicing, at Honfleur, 464.
Bateman, J. F., Past-President, consulted in reference to floods of the Irwell, 241.—Remarks as to ditto, 254.—Ditto as to simultaneous rising and falling of the tide in the same river, 254.—Ditto as to general considerations in devising plans for river improvements, 255.—Ditto as to a flood in the Medlock in 1833, 255.—Ditto ditto Etherow in Longendale, 1852, 255.—Ditto as to the flow at the Manchester Waterworks on various noteworthy occasions, 256, 257.—Ditto

Digitized by Google

ditto Glasgow Waterworks, 257.—Ditto river Clyde at Glasgow, 257.—His connection with the Bann Reservoirs, 317 *et seq.*

Bauschinger, Professor J., on variations in the limit of elasticity, and in the modulus of elasticity of various metals, 432.—Experimental proofs of some new formulæ for the torsion of prismatic bodies, 435.—Iron ore from Amberg, Bavaria, 483.

Baynes, J. H., admitted student, 199.

Beam, simple, graphical integration as applied to the statics of the, 429.

Beare, T. H., admitted student, 199.

Bedford Level, physical characteristics of the, 203 *et seq.*

Belgian rolled iron girders, transverse breaking strain of, 28.

Belin, A. Z. C., elected associate member, 200.

Bell, A. W. D., elected associate member, 200.

——, G., elected associate member, 200.

Belmont, rainfall at, 236.

Benedict, E., remarks as to metallic permanent way, 61.—Ditto as to the efficiency of the cast-iron bowl sleepers used in India, 61.

Bentzen, C., elected associate member, 200.

Bergeron, C., remarks as to metallic permanent way, 53.—Ditto as to an experiment on the flexure of rails carried out by Professor Willis, Captain Galton, and Sir H. James, 53.—Ditto as to the influence of the ballast on the resistance of the sleepers, 53.—Ditto as to the best way of laying the ballast, 54.—Ditto as to the permanent way of the Northern Railway of Spain, 54.—Ditto as to experience on the Swiss railways proving the advantage of embedding the ballast in the formation, 56.—Ditto as to a system of iron permanent way with continuous bearers of inverted trough section, 57.

Best, H. R., admitted student, 199.

Bird, G. R., elected associate member, 200.

Blackett, J. W., elected associate member, 200.

Blair, J. M., remarks as to metallic permanent way, 38.—Ditto as to Le Crenier's iron sleeper used on the Portuguese railways, 38.—Ditto as to different systems of iron sleepers, 39.—Ditto as to corrosion, 39.—Ditto as to the steel sleepers used on the Oude and Rohilkund Railway, 40.—Ditto as to a means of obviating the chattering of metallic sleepers, 41.—Ditto as to experiments on embossed steel sleepers at the Clutha ironworks, 41.—Ditto as to Dr. Angus Smith's anti-rust composition for sleepers, 42.—Ditto as to varieties of the embossed steel sleepers, 43.

Blast furnace, manganese, the theory of the, 494.

Blasting under water, 450.

Blum, R., "The Current-Meter of Professor A. R. Harlacher," 358.

Bolton, rainfall at, 236.

Bonnaud, A., steel wire for ropes, 509.

Borries, — von, on the working of local passenger traffic on railways, 473.

Boston, floods in the Witham at, 205 *et seq.*

Boucher, A., remarks as to the failure of iron sleepers, of the Vautherin type, on the Northern of France railway, 68.

Bousfield, W. R., remarks as to the elastic field gun-carriage, 152.—Ditto as to some misapprehensions of the mathematical theory of recoil in Mr. Butter's Paper, 152.—Ditto as to the difference of recoil with R. L. G. and with pebble powder, 155.—Ditto in explanation of his previous remarks, 162.

Bowl sleepers. *Vide* Permanent Way.

Digitized by Google

Boyd, R. N., elected member, 200.
Bramwell, Sir F., Vice-President, remarks as to the elastic field gun-carriage, 159.—Ditto as to the possible strain on the trunnion of a gun, 159.—Ditto as to the asserted greater recoil with large grain than with pebble powder, 161.
Bridge, foot-, rolling over the Duquesne lock at Dieppe, 454.
Bridgwater Navigation Company and the conservancy of the Irwell, 237.
Briggs, J. H., elected associate member, 200.
Browne, W. R., opinion of, on the value of tidal scour, referred to, 220.—Remarks as to the conservancy of rivers, 299.—Ditto as to river floods having been more serious of late years, 299.—Ditto as to the advisability of suppressing mill rights where they interfered with the free passage of flood water, 299.—Ditto as to tidal scour, 300.
Bruce, G. B., remarks as to metallic permanent way, 44.—Ditto as to the probable reason why English engineers had not generally adopted iron sleepers, 44.—Ditto as to Webb's sleeper, 45.—Ditto as to the difficulty of packing metallic sleepers, 45.—Ditto as to the first metallic sleepers used in India, 45.
Brunel, I. K., endeavours of, to substitute iron for wood for the permanent way of the Great Western railway, 83.
Brunon sleepers tried on the Paris, Lyons, and Mediterranean railway, description of the, 73.
Brunton, J., "The Oxford and District Tramways," 345.
————, W., memoir of, 395.
Buck, J. H. W., "The Weights of Framed Girders and Roofs," 331.
Bull, J., elected associate member, 200.
Bunning, C. Z., admitted student, 199.
Bunte, Dr., experiments on the manufacture of water-gas, 480.
Butler, J. S. elected associate member, 200.
Butt, H. W., elected associate member, 200.
Butter, H. J., "Forces and Strains of Recoil considered in relation to the Elastic Field Gun-Carriage," 123.—Remarks as to ditto, 142.—Ditto as to the value of the formula $V = \frac{v\,w}{W}$, 142.—Ditto as to the mathematical processes by which he arrived at the results given, 162.—Ditto as to the time and space values of pressure diagrams, 162.—Ditto as to Dr. Siemens's connection with the hydraulic buffer, 163.—Ditto as to the spring originally intended to be used inside the buffer, 163.—Ditto as to the object of the elastic carriage, 164.—Ditto as to the criticisms of the mathematics of his paper, 164 *et seq.*, 192.—Ditto as to the proposition for preventing recoil by opposing a resistance equal to that of the maximum powder-pressure, 192.—Ditto as to Colonel Sebert's experiments with the velocimeter, 192.—Ditto as to Mr. Vavasseur's invention of a similar carriage to his own, 193.—Ditto as to the objections against his employment of the term dynamic force, 194.—Ditto as to the case of a gun developing an energy approaching that of the shot, 194.—Ditto as to Dr. Pole's mathematical investigation of recoil, 196.—Ditto as to some recent experiments on the resistance of inertia, 196.
Buyers, J. W., elected member, 200.

Cameron, E. A., elected member, 200.
Campbell, Colonel, R.E., his plan for affording relief for the flood-water of the river Bann, referred to, 322.

Digitized by Google

Canal, Banbridge and Newry Navigation Junction, practical construction of, referred to, 323.
———, Suez, constant dredging necessary to maintain the, 292.
——— -lift, hydraulic, at Fontinettes, near St. Omer, 451.
Canalisation of the Fen rivers in the seventeenth and eighteenth centuries, 215.
Canet, G., remarks as to the elastic field gun-carriage, 173.—Ditto as to the nature of inertia, 174.—Ditto as to some experiments made at Calais in 1872 to find the influence of the centre of gravity of common shells on their flight, 174.—Ditto as to the experiments of Colonel Sebert with his velocimeter, 178.—Ditto as to the elastic gun-carriage designed by Mr. Vavasseur, 178.
Carriage, elastic field. *Vide* Gun-carriage.
Carrington, W. T. H., transferred member, 199.
Cawley, C. E., consulted as to floods in the Irwell, 241.
Cement, Portland. "Results of Experiments with Portland Cement gauged with Sea and Fresh Water under different conditions," 349.—Object of the experiments, 349.—Form of briquette adopted, 350.—Results of tests, 351.
Chapman, H. B., elected associate member, 200.
Chauntler, F., elected associate member, 200.
Christie, E. J, H., elected associate member, 200.
———, H. B., elected associate member, 200.
Civil engineering in Italy. *Vide* Italy.
Clericetti, Prof. C., the great structures erected in Italy during the last twenty years, 440.
Clerk, Colonel H., R.A., his acknowledgment of Dr. Siemens's suggestion of hydraulic buffers for gun-carriages, referred to, 149.
Clutterbuck, Rev. J. C., remarks as to the conservancy of rivers, 301.—Ditto as to the establishment of conservancy boards armed with full powers, 301.—Ditto as to the Thames, 301.—Ditto as to the evaporation from the soil, 302.—Ditto as to the advisability of confining the action of a Conservancy Board to the main stream, 301.
Coal, borings for, in the south of France, 499.
——, cleaning, by an air blast, 504.
Coignet, F., American stamps for gold and silver ores, 497.
Cold, action of, on the voltaic arc, 523.
——, extreme, influence of, in retarding the adoption of iron permanent way, &c.
Collieries, underground roads in, timbering, 403.
Colquhoun, A. R., elected associate member, 200.
Condensers, electric, chains of tubes forming, 529.
Congress of electricians (Paris, 1881), units adopted by the, 522.
Conservancy boards, multiplicity of, in the Fen districts, 251.—Table of, having jurisdiction over the Nene between Peterborough and Wisbech, 252.—Ditto, over parts of the river Hull, 258.
——— of rivers. *Vide* Rivers.
Conservation of electricity. *Vide* Electricity.
Coode, Sir J., observations made by, on the river Nene, referred to, 209.—Remarks as to the conservancy of rivers, 249.—Ditto as to the general principles accepted by engineers in river improvement, 249.—Ditto as to the throttle of the Nene at Wisbech, 250.—Ditto as to reservoirs, 250.—Ditto as to the conditions which produced flooding, 250.—Ditto as to the multiplicity of authorities in the Fen districts, 251.—Ditto in explanation of his previous remarks, 257.
Cooper, C. F., elected associate member, 200.

Digitized by Google

Coote, T., remarks as to the conservancy of rivers, 239.—Ditto as to the river Ouse, 269.—Ditto as to storage reservoirs, 269.
Cörper, H., the measurement of speed on railways, 466.
Corrosion, influence of, on iron permanent way material, 22 *et seq.*
Coulon, R., duration of induced currents, 530.
Cowper, E. A., remarks as to metallic permanent way, 28.—Ditto as to the backward position of English engineers in respect of the application of iron and steel as permanent way materials, 28.—Ditto as to Webb's steel sleeper on the London and North Western Railway, 29.—Ditto as to the progress of metallic sleepers in Germany, 29.—Remarks as to the elastic field gun-carriage, 144.—Ditto as to the hydraulic buffer, 144.—Ditto as to the gas pressure acting inside the gun against the breech, 145.—Ditto as to the friction of the gas-check, 146.—Ditto as to the rifling of the first Lancaster gun, 146.—Ditto as to the insufficiency of simply gauging the greatest pressure, 146.—Ditto as to the apparatus for registering recoil, 147.—Ditto as to a means of registering the exact times of the pressures, 147.
Cregeen, A. C., transferred member, 199.
Croft, H., elected associate member, 200.
Cudworth, W., remarks as to the trials of Wood's iron sleepers on the North Eastern Railway, 68.
Culverwell, G. P., elected associate member, 200.
Cunningham, G., elected member, 200.
Current meter. "The Current Meter of Professor A. R. Harlacher," 358.—Disadvantages of the meters in general use, 358.—Construction of the Harlacher meter, 359.—Mode of using it, 364.—Appendix: formulæ used with the Harlacher meter for determining the velocity of the water, 366.
Currents (electric), induced, duration of, 530.
———, on the absolute measurement of, by electrolysis, 529.
Curves. Note on a new method of printing barometer- and other curves, 521.

D'Arsonval, Dr. A., the efficiency of electric motors, 527.
D'Avigdor, E. H., remarks as to the transverse breaking strain of Belgian iron girders, 28.
Daburon, H., timbering underground roads in collieries, 503.
Daelen, —, his iron permanent way on the Kreienzen and Holzminden railway referred to, 6.
Davey, H., remarks as to the elastic field gun-carriage, 179.—Ditto as to the formula $V W = v w$ for ascertaining the maximum velocity of recoil, 179.—Ditto as to the action of exploded gunpowder, 180.—Ditto as to the hydraulic buffer, 180.
Davison, R., Jun., elected associate member, 200.
Dawbarn, G., remarks as to the conservancy of rivers, 277.—Ditto as to the present private-bill system being utterly useless to remedy the existing evils, 277.
Dawson, Commander, W., R.N., remarks as to the elastic field gun-carriage, 156.—Ditto as to the mode of measurement of the forces and strains on the carriage, 156.—Ditto as to short recoil being more destructive on board ship than long recoil, 156.—Ditto as to the action of different sorts of gunpowder, 157.—Ditto as to gun-cotton, 157.
———, W. A., remarks as to metallic permanent way, 59.—Ditto as to Legrand's system, 59.

Digitized by Google

Deblanc, —, new kineto-electric machine, 534.
Demoly, A., remarks as to metallic permanent way, 68.—Ditto as to the use of iron sleepers of the Vautherin type on the Algerian lines of the Paris, Lyons, and Mediterranean railway, 69.—Ditto as to a metallic sleeper designed by himself for use in hot countries, 70.—Ditto as to the difficulty of keeping tight the fastenings in ordinary iron sleepers, 71.
Denham-Olpherts sleeper described, 37.
Denver sluice, erection of, referred to, 214.
Deprez, M., magnetic speed-meter, 540.
Deutsch, J., blasting under water, 450.
Devonshire, Duke of, K.G., elected honorary member, 200.
Dick, G. G., transferred member, 199.
Diggle, J., elected associate member, 200.
Dix, H. A., admitted student, 199.
Dixon, H. W. T., admitted student, 199.
Dombes and South Eastern railway of France, stone block sleepers used on the, 82.
Drainage of the Bedford Level referred to, 203 *et seq.*
Dundee tramways. *Vide* Tramways.
Dupuy de Lôme, —, his studies on aerial navigation referred to, 374 *et seq.*
Duquesne lock at Dieppe. *Vide* Lock.
Dynamo-machines, experiments on, 530.

Eachus, G. E., remarks as to the conservancy of rivers, 268.—Ditto as to the proposed tunnel for passing off the flood waters of the Irwell, 268.—Ditto as to storage reservoirs, 268.
Eau Brink Cut. *Vide* River Ouse.
Edwards, O. A. G., admitted student, 199.
Elasticity of metals. *Vide* Metals.
———— timber. *Vide* Timber.
Electric charges which cover two metals in contact, on the difference of potential of the, 528.
——— condensers. *Vide* Condensers.
——— lamp. *Vide* Lamp.
——— light. *Vide* Light.
——— motors, the efficiency of, 527.
Electrical apparatus, measurement of the energy given to, 526.
———— thermometers. *Vide* Thermometers.
———— units. *Vide* Units.
Electricity, conservation of, principle of the, or second principle of the theory of electrical phenomena, 523.
————, transmission of power by, on the yield and the limit of the operation of the, 524.
Electrolysis, on the absolute measurement of currents by, 529.
Ellis, R. E., admitted student, 199.
Elworth, H., remarks as to metallic permanent way, 71.—Ditto as to the greater cheapness of wood precluding the present use of iron sleepers in Sweden, 71.
Engelhardt Russian field gun-carriage, 136.
Erewell spring, source of the river Irwell, 234.
Escott, E. R. Sweet, elected member, 200.
Evans, W., elected member, 200.

Digitized by Google

Exall, W., memoir of, 405.
Explosives, researches on by Captain Noble and Professor Able, referred to, 122 *et seq.*

Faija, H. "Results of Experiments with Portland Cement gauged with Sea and Fresh Water under different conditions," 349.
Fairbairn, Sir W., his connection with the Bann Reservoir Company, 317 *et seq.*
Fens, the, physical characteristics of the, 203 *et seq.*
Fidler, T. C., joint-engineer of the Oxford tramways, 345.
Field, F. A., admitted student, 199.
Finnimore, B. K., admitted student, 199.
Fitzjames, F., memoir of, 396.
Fitzmaurice, W. R., admitted student, 199.
Flood of 16th November, 1866, in England, 237.
Floods in rivers. *Vide* Rivers.
Foote, E. C., admitted student, 199.
Forquignon, —, malleable cast iron and the annealing of steel, 492.
Fox, D. M., his experience of the iron permanent way on the Great Western railway referred to, 1 *et seq.*
—— F. (Bristol), remarks as to metallic permanent way, 71.—Ditto as to the Macdonnell, or Adams, sleepers used on the Bristol and Exeter section of the Great Western railway, 72.
France, conservancy of rivers in, 247, 303, 308 *et seq.*—Borings for coal in the South of, 499.
Frankel, Dr. W., self-recording indicator of the elastic extensions of loaded bars, 428.
Fraser, E. G., elected associate member, 200.
Frolich, Dr. O., on dynamo-machines, 530.
Fteley, A., the flow of the Sudbury river, Massachusetts, for the years 1875-79, 448.
Fulton, J. E., elected associate member, 200.

Galton, Captain D., James, Sir H., and Willis, Professor, experiments of, on the flexure of rails referred to, 52.
Garcenot, A., wire ropes, 506.
Garet, A., remarks as to metallic permanent way, 73.—Ditto as to the Ménans, Brunon, and PLM. types of iron sleepers tried on different sections of the Paris, Lyons and Mediterranean railway, 73.
Gas-mains, the laying of, and the means of discovering and repairing leaks in them, 477.
Gas, water, experiments on the manufacture of, 480.
Gaskin, D. M. F., transferred member, 199.
German telegraph system, Imperial, the underground conducting network of the, 537.
Germany, conservancy of rivers in, 246, 304.
Giffard, H., account of his dirigible balloon, 372 *et seq.*
Giles, A., remarks as to the conservancy of rivers, 269.—Ditto as to the divided jurisdiction at Lincoln, 269.—Ditto as to the Begehungs Commission in Austria, 269.—Ditto as to the necessity for legislation as to the management of rivers, 269.—Ditto as to the river Parret near Bridgwater, 270.—Ditto as

Digitized by Google

to its not being possible to lay down general rules for the drainage of rivers in England, 270.
Girders. "The Weights of Framed Girders and Roofs," 331.
Glass, J. G. H., transferred member, 199.
Golborne, J., his report of 1769, on the river Nene referred to, 211.
Gowans' system of permanent way for tramways used in Dundee, 338.
Grand Sluice at Boston, effect of, on floods in the Witham, 206.
Grantham, R. B., remarks as to river conservancy, 263.—Ditto as to inquiries held by him under the Land Drainage Act, 263.—Ditto as to the expediency of each watershed being formed into a drainage district, 264.—Ditto as to the navigation of the Ouse at Bedford, 264.—Ditto as to the effect of constant pumping from the Fen lands, 264.
Granville, Earl, K.G., elected honorary member, 200.
———, H. C., elected associate member, 200.
Graphical integration as applied to the statics of the simple beam, 424.
Greenhill, Professor A. G., remarks as to the elastic field gun-carriage, 180.—Ditto as to Mr. Butter's experiments on the velocity of recoil, 180.—Ditto as to the action of the air in increasing recoil, 181.—Ditto as to inertia, 181.—Ditto as to a means of more accurately determining recoil, 182.
Greenwood, A., elected member, 200.
Greig, A. "Extension of the Dundee Street Tramways," 338.
Gresley, W. S., elected associate member, 200.
Griffin, B., elected associate member, 200.
Gros, L., remarks as to the conservancy of rivers, 303.—Ditto as to the floods of the Theiss at Szegedin in 1879, 303.
Guillaume, —, report of, on the trials of different types of metallic sleepers on the Eastern railway of France, 78.
Gun-carriage. "Forces and Strains of Recoil considered with reference to the Elastic Field Gun-carriage," 122.—Questions relating to the action of powder pressure on the projectile already settled, 122.—Usual formula for recoil, 123.—Effects produced when a powder charge is exploded in the chamber of a gun, 124.—Influence of the kind of powder on the pressures produced by its explosion, 126.—Time-curves of recoil taken during the discharge of a 10-inch gun, 127.—Conditions to be met in designing a carriage for the 12½-pounder gun, 129.—The elastic field carriage, 130.—Mode of ascertaining the strains set up by any gun upon its carriage, 133.—Functions of the hydraulic buffer, 134.—Experiments to determine the correctness of the assumption that the pressure curves of recoil represent the energy of recoil less friction and gravity, 136.—Method of testing the results arrived at, 139.—Conclusions deduced from the experiments, 140.
Gunpowder, pressures produced by the explosion of, in the chamber of a gun, 122 *et seq.*

Haarmann, —, his system of permanent way on the Cologne-Minden railway referred to, 17.
Hack, H., elected member, 200.
Hagen, G., remarks as to the conservancy of rivers, 304.—Ditto as to the influence of cultivation of the soil on floods, 304.—Ditto as to the action of the Imperial German Parliament on the subject of floods, 305.—Ditto as to his investigations of the water levels of various Prussian rivers, 305.
Hallé, G., elected associate member, 200.

Digitized by Google

Hamilton-Smythe, A. J., remarks as to metallic permanent way, 118.—Ditto as to the importance of designing any system of metallic sleepers, so as to take the steel rails now generally used, 119.—Ditto as to burying the sleeper in the ballast, 119.—Ditto as to the horizontal feet of the Vautherin sleeper, 119.—Ditto as to curving the sleeper for tilt, 119.
Hammett, —, opinion of, as to the Macdonnell permanent way on the Bristol and Exeter and Bridport lines of the Great Western railway, 4, 72.
Harbours on sandy coasts, on the construction of, 455.
Hargrave, H. W., admitted student, 199.
Harker, H. H., elected associate member, 200.
Harlacher, Prof. A. R., the current meter of, 358.
Harrison, F. R., admitted student, 199.
———, J. T. and Rawlinson, R., C.B., reports of, on the Thames, the Lee, and the Aire and Calder, referred to, 293.
Hartig, Dr. E., experiments on the work done by reaping machines, 512.
Hartley, R. J., admitted student, 199.
Hartwich, E., his iron permanent way on the Prussian-Rhenish railway, referred to, 6.
Haslingden, rainfall at, 236.
Hawkins, R. W. L., elected associate member, 200.
Hawkshaw, J. C., remarks as to river conservancy, 259.—Ditto as to floods of the river Witham and its tributaries, 259.—Ditto as to the obstruction of the waterway of rivers by towns, as exemplified at Peterborough, Norwich, Oxford, and Burton-on-Trent, 261.—Ditto as to legislation on river conservancy, 261.—Ditto as to flood lines, 262.—Ditto as to flood lands in Holland, 263.
Hawksley, T., Past-President, consulted in reference to floods of the Irwell, 241.
Head, J., memoir of, 397.
Heathorn, Capt. T. B., late R.A., elected associate, 201.
Henriques, C. Q., elected associate member, 200.
Heusinger von Waldegg, E., his system of iron permanent way, referred to, 10.
Hiard, L., machine-made muffles for zinc-smelting, 496.
Hilf, —, his systems of iron permanent way described, 7 *et seq.*
Hodges, R. N., elected associate member, 200.
Hogan, J. P., elected associate member, 200.
Hohenegger, W., his iron permanent way on the North Western railway of Austria, 10.
————————, remarks as to Mr. Wood's modification of the Vautherin sleeper, 77.
Honfleur, the sluicing basin at, 464.
Hoppin, A., American milling methods, 513.
Hospitalier, E., the various systems of electric light, 534.
Howard, J. H., admitted student, 199.
Hughes, A. J., elected member, 200.
Hunter, J. B., elected associate member, 200.
Hutton, C. H., admitted student, 199.
———, W. S. H., admitted student, 199.
Hydraulic canal lift at Fontinettes, near St. Omer, 451.

Indicator, self-recording, of the elastic extensions of loaded bars, 428.
Induced Currents. *Vide* Currents.
Inertia, nature of, in respect of the recoil of guns, 152 *et seq.*

Digitized by Google

Ingleby, R., letter of, as to the great flood of the river Nidd in Feb. 1868, 290.
Inland navigation in England, decay of, since the era of railways, 214.
Iron, malleable cast, and the annealing of steel, 492.
——, quality of, determination of the, 438.
—— ore from Amberg, Bavaria, 483.
—— permanent way. *Vide* Permanent Way.
—— railway sleepers, mode of manufacture of, 24.
—— and steel, on a producer's classification of, 484.
——, wrought, and steel, strength of, at high temperatures, experiments on the, 437.
Italy, the great structures erected in, during the last twenty years, 440.

Jack, A. J., admitted student, 199.
Jacob, A. "The Conservancy of Rivers: the Valley of the Irwell, 233."—Remarks as to ditto, 249.—Ditto as to the great flood in Salford in 1866, 249.—Ditto as to the difference between the Irwell and the Fen rivers, 297.—Ditto as to inapplicability of contour levels to the basin of a river like the Irwell, 297.—Ditto as to the proposed relief tunnel at Salford, 297.—Ditto as to the immunity from floods in Salford being merely a question of money, 298.—Ditto as to the equity of compelling the navigation companies, mill owners, &c., to contribute to the improvement of the rivers they used, 298.—Ditto as to the evils of solid weirs, 298.—Ditto as to the gaugings of the Irwell during the great flood of 1866, 298.—Ditto as to the relative advantages of dredging and embanking, 299.
Jacomb, W., remarks as to the type of permanent way adopted as a standard on the South Western railway, 77.
James, C., elected associate member, 200.
——, Sir H., Willis, Prof., and Galton, Capt., experiments of, on the flexure of rails, 52.
Jedlik, Dr. A., chains of tubes forming electric condensers, 529.
Jeffreys, E. H., elected associate member, 200.
Jenkin, Prof. H. C. F., remarks as to the elastic field gun-carriage, 182.—Ditto as to the inequality of recoil observed with different powders, and Mr. Butter's explanations of its reason, 182.
Johns, W. A., admitted student, 199.
Johnstone, Capt. W. H., R.E., memoir of, 415.
Jones, J. A., transferred member, 199.
——, C. B., elected member, 200.
Joyner, H. B., transferred member, 199.

Keller, H., on the formation of sandbanks and sandhills, and the construction of harbours on sandy coasts, 455.
Kineto-electric machine, new, 534.
King, T., admitted student, 199.
Kirsch, —, his system of iron permanent way referred to, 11.
Kyd, A. A., admitted student, 199.
Kyle, J., Jun., admitted student, 199.

Laffert, Lieut. von, use of the telephone as a means of communication during the training of infantry in shooting, 541.
Lagréné, H. de, remarks as to the conservancy of rivers, 308.—Ditto as to the

Digitized by Google

importance of considering the river valley as a whole and not undertaking piecemeal improvements, 309.—Ditto as to works designed specially for preventing floods, 309.—Ditto as to navigation works, 310.
Lambert, G. N. R., elected member, 200.
Lamp, electric, L. Scharnweber's, 536.
Lancaster gun, construction of the first rifling-machine for the, referred to, 146.
Landes, the, of France, growth of timber for railway sleepers on the, 84.
Latham, B., remarks as to the conservancy of rivers, 275.—Ditto as to the river Ouse, 275.—Ditto as to Denver sluice, 276.—Ditto as to the action of the tidal wave, 276.—Ditto as to the works in the Fens having been all begun at the wrong end, 277.
Lauer's system of blasting under water, 450.
Lavoisier's summary of the conditions to be fulfilled in aerostatic machines, referred to, 371.
Lavollée, —, contrivance for working the needles at the new overfall at Port-à-l'Anglais weir, 453.
Law, H., remarks as to metallic permanent way, 45.—Ditto as to the alleged superior stability of a cross sleeper as compared with a longitudinal roadway, 45.—Ditto as to the importance of considering the wear and tear of the rolling stock in any system of permanent way, 46.
Leaks in gas-mains, discovery and repair of, 477.
Le Crenier's iron sleepers used on the Portuguese railways, 38.
Ledebur, A., theory of the manganese blast furnace, 494.
Ledru, C., remarks as to metallic permanent way, 78.—Ditto as to a report of Mr. Guillaume on the trials of different types of iron sleepers on the Eastern railway of France, 78.—Ditto as to the weak points of metallic sleepers and their fastenings, 79.
Lefébure, E. E., admitted student, 199.
Legrand's iron sleepers for collieries, referred to, 49 *et seq.*
Léonard. *Vide* Basiaux.
Leslie, B., remarks as to metallic permanent way, 37.—Ditto as to the early abandonment of wooden sleepers in India, 37.—Ditto as to the good service of cast-iron sleepers in India, 37.—Ditto as to the Denham-Olpherts sleeper on the East Indian railway, 37.
Levelling apparatus for measurement of base lines, 421.
——— staves, wooden, changes in length of, 421.
Levy, —, on the yield, and the limit of the operation of the transmission of power by electricity, 524.
Leyland, J., notes made by, of the flood of the river Wharfe, in December 1869. —290.
Lift, canal, hydraulic, at Fontinettes, near St. Omer, 451.
Light, electric, the various systems of, 534.
Lightfoot, T. B., elected member, 200.
Lincoln, floods of the Witham, in, 206 *et seq.*
Lindner, M., electrical thermometers for observing temperature at a distance, 540.
Lippmann, G., principle of the conservation of electricity, or a second principle of the theory of electrical phenomena, 523.
Livesey, J., his sheet-iron railway sleeper referred to, 20.—Remarks as to metallic permanent way, 29.—Ditto as to some experiments with cast-iron sleepers on the North London railway, 28.—Ditto ditto with wrought-iron sleepers on the Great Eastern line, 30.—Ditto as to the most suitable form for a wrought-iron

Digitized by Google

sleeper, 31.—Ditto as to the sleepers of plate iron used on the Great Eastern railway, 31.—Ditto as to closed-end sleepers, 33.—Ditto as to the best ballast for metallic permanent way, 33.—Ditto as to the relative advantages of transverse and bowl sleepers, 35.—Ditto as to rail fastenings, 35.—Ditto as to the merits of the transverse sleeper with bowl-formed ends, 35.—Ditto as to the objections to Mr. Charles Wood's sleeper and fastenings, 38.—Ditto as to the adoption of his iron sleeper by the Indian Government, 51.

Local traffic on railways. *Vide* Traffic.

Lock, Duquesne, Dieppe, rolling foot-bridge over the, 454.

Longitudinal and cross-sleeper systems of permanent way, comparative advantages of, 22 *et seq.*

Longridge, J. A., remarks as to the elastic field gun-carriage, 183.—Ditto as to the formula $V W = v w$, 183.—Ditto as to some ambiguities in the mathematical terms employed in Mr. Butter's Paper, 183.—Ditto as to the hydraulic buffer, 185.

Lough Erne improvement works, account of the, 314.

Lucas, J., remarks as to the conservancy of rivers, 289.—Ditto as to the impossibility of constructing a hydrographic map of a river basin from existing information, 289.—Ditto as to the proposal to establish flood lines, 289.—Ditto as to the flood of the river Nidd in 1868, 289.—Ditto as to the annual flooding of the Castle Mill at Dorking, 291.—Ditto as to the necessity of a central office for the control of all matters of river conservancy, 291.

Lynch, F. J., elected member, 200.

Lynn, effect of the floods of the Ouse on, 212.

McAlpine, J. L., elected member, 200.

MacAvoy, remarks as to the elastic field gun-carriage, 185.—Ditto as to the hydraulic buffer, 185.—Ditto as to the propagation of powder pressure, 186.—Ditto as to the employment of quick-burning powder, 186.—Ditto as to experiment alone being able to determine the points contested in regard to recoil, 187.

McDonald, J. A., elected associate member, 200.

Macdonnell, J. J., his system of iron permanent way referred to, 3 *et seq.*

McIlwraith, T., elected associate, 201.

Mackison, W., his system of permanent way for tramway as laid in Dundee, 338 *et seq.*

McMahon, —, report on the drainage of the lands bordering Lough Neagh referred to, 321.

Magnetic after-effect. *Vide* After-effect.

——— speed-meter. *Vide* Speed-meter.

——— waves. *Vide* Waves.

Magnetism of Steel. *Vide* Steel.

Magnets, on the manufacture of, 538.

Main, J. F., elected associate, 201.

Malézieux, E., remarks as to the conservancy of rivers, 311.—Ditto as to the views held officially in France on the prevention of floods, 311.—Ditto as to the form of embankments specially adopted for the river Loire, 311.—Ditto as to the insufficiency of reservoirs to cope with floods, 312.—Ditto as to the system of flood warnings organised in France, 312.—Ditto as to police regulations, 313.—Ditto as to replanting mountains, 313.—Ditto as to the preservation of fish, 314.

Digitized by Google

Mallet, R., his views on the construction of artillery referred to, 171.
Manchester Corporation Waterworks. *Vide* Waterworks.
Manganese blast furnace. *Vide* Blast Furnace.
Mangini, —, remarks as to the stone block system of permanent way adopted for the lines of the Dombes and South Eastern railway of France, 82.
Mann, J. R., admitted student, 199.
Manning, R., report of the Bann floods, referred to, 320 *et seq.*
Marchant, F. W., elected associate member, 200.
Marsh, T. E. M., opinion of, as to the iron permanent way on the Great Western railway, 3.—Remarks as to metallic permanent way, 83.—Ditto as to the history of the early endeavours of Mr. Brunel to substitute iron for wood for the permanent way of the Great Western railway, 83.—Ditto as to Webb's steel sleeper, tried on the London and North-Western railway, 83.—Ditto as to the Barlow rail and sleeper tried on the Great Western, 83.
Marten, H. J., remarks as to river conservancy, 264.—Ditto as to the "Rivers Conservancy and Floods Prevention Bill," 265.—Ditto as to the definition of the term "conservancy of rivers," 265.—Ditto as to a proposed General Conservancy Board for each watershed, 266.—Ditto as to the flood of the Irwell in November 1866, 267.
Martin, W., admitted student, 199.
Martineau, W., remarks as to metallic permanent way, 59.—Ditto as to the question of corrosion, 59.—Ditto as to the end-shifting of longitudinal sleepers, 59.
Mascart, E., on the absolute measurement of currents by electrolysis, 529.
Mathieu, H., remarks as to metallic permanent way, 84.—Ditto as to the greater cheapness of wood sleepers in the districts traversed by the Southern railway of France, 84.—Ditto as to the type of wooden permanent way adopted on that line, 84.
Mazzocchi, L., the river Olona conservancy, 447.
Measurement of the energy given to electrical apparatus, 526.
Ménans sleepers tried on the Paris, Lyons, and Mediterranean railway, description of the, 73.
Mercadier, E., application of the radiophone to telegraphy, 537.
Meridian, Paris, on the extension of the, to the Sahara, 422.
Metallic permanent way. *Vide* Permanent Way.
Metals, various, on variations in the limit of elasticity, and in the modulus of elasticity of, 432.
Meter, current, the, of Professor A. R. Harlacher, 358.
Michell, W., elected associate member, 200.
Mill, Castle, at Dorking, annual flooding of the, referred to, 291.
Millhouse, W., elected associate member, 200.
Milling methods, American, 513.
Mitchell, J. E., admitted student, 199.
Montgolfier's balloon, early attempts at aerial navigation with, 370.
Moreing, C. A., elected associate member, 200.
Motors, electric, the efficiency of, 527.
Muffles, machine-made, for zinc-smelting, 496.

Nimmo, A., report of, on the supply of water to the Newry navigation referred to, 322.
Noble, A., C.B., elected member, 200.

Digitized by Google

Noble, Captain W. and Abel, F. A., their "Researches on Explosives" referred to, 122 *et seq.*
Norwich, impediments offered to the passing off of floods at, 261.
Nuttall, J. H., elected associate member, 200.

Oliver, R. S., elected associate member, 200.
Olsen, H. B., elected associate member, 200.
O'Neill, W. J., report of, on the Bann floods, referred to, 320 *et seq.*
Oppenheim, —, the laying of gas-mains and the means of discovering and repairing leaks in them, 477.
Ores, stamps for. *Vide* Stamps.
Osmond, W., admitted student, 199.
Oxford, floods of the Thames and the Cherwell at, 261.—Tramways of. *Vide* Tramways.

"P L M" iron sleepers tried on the Paris, Lyons, and Mediterranean railway, 73.
Palmer, C. S. R., admitted student, 199.
Pattenhausen, —, on the extension of the Paris meridian to the Sahara, 422.
Pebble powder, action of, in respect of the recoil of guns, 124 *et seq.*
Pellat, H., difference of potential of the electric charges which cover two metals in contact, 528.
Penny, A. R., admitted student, 199.
Perkins, A. M., memoir of, 417.
Permanent way of railways. "Iron Permanent way," 1.—Development of iron permanent way on the Continent, 1.—*Longitudinal sleepers:* Barlow's sleepers, 3.—Macdonnell's iron sleepers on the British and Exeter railway, 3.—Bridges Adams' system, 5.—Hartwich's, 6.—Scheffler's, 6.—Daelen's, 6.—Hilf's, 7.—Prussian Rhenish system, 9.—Hohenegger's, 10.—Heusinger von Waldegg's, 10.—Kirsch's, 11.—Winkler's, 11.—Haarmann's, 12.—De Serres and Battig's, 12.—*Transverse sleepers:* Le Crenier's channel iron sleepers, 13.—Couillet Forge Company's system, 13.—Barningham's, 14.—Vautherin's, 14.—Bergisch-Märkisch, 15.—Prussian Rhenish, 16.—Haarman's, 17.—Wood's sleepers on the Middlesbrough railway, 18.—Reynold's wrought-iron sleeper with cast-iron chain, 20.—Livesey's compressed sheet iron sleeper, 20.—Webb's steel sleeper, 21.—Ballast best adopted for use with metallic permanent way, 21.—Slight effects to be apprehended from the oxidation of metallic sleepers, 22.—Greater stability of transverse than of longitudinal sleepers, 23.—Precautions necessary in the manufacture of metallic permanent way, 24.—Necessity of good fishing, 25.—Comparative cost of metallic and wooden permanent way, 26.
Peterborough, floods in the Nene at, 209 *et seq.*
Pewtress, H. W., admitted student, 199.
Philpot, J. M., admitted student, 199.
Pictet, R., a comparative study of different qualities of steel, as regards magnetism and its permanency, 520.
Polarity, permanent in steel, on a case of, opposed to that of the magnetising coil, 538.
Pole, W., remarks as to the elastic field gun-carriage, 187.—Ditto as to a mathematical determination of recoil according to the ordinary laws of mechanics, 187.

Digitized by Google

"A Study of the Problem of Aerial Navigation, as affected by Recent Mechanical Improvements," 369.
Pot sleepers. *Vide* Permanent way.
Potier, A., the measurement of the energy given to electrical apparatus, 526.
Portland cement. *Vide* Cement.
Power, transmission of, by electricity, on the yield and the limit of the operation of, 524.
Pressel, W., the ventilation and cooling of Alpine tunnels, 442.
Prevention of floods. *Vide* Rivers.
Price, J., remarks as to the conservancy of rivers, 314.—Ditto as to the works in the Loughs and river Erne, 314.—Ditto as to keeping the river channels small to avoid weeds, 315.—Ditto as to the possibility of combining drainage, mill power, and navigation, 315.—Ditto as to the provision of artificial flood lands 315.—Ditto as to adopting a hyperbolic form for river channels and maintaining it by dredging, 315.—Ditto as to the success of the Lough Erne works, 315.
Projectiles, action of exploded gunpowder on, referred to, 122 *et seq.*

R. L. G. powder, action of, in respect of the recoil of guns, 124 *et seq.*
Radiophone, application of the, to telegraphy, 537.
Railway, Brunswick, Scheffler's system of iron permanent way, on the, 6 *et seq.*
———, Cologne-Minden, Haarmann's iron permanent way on the, 17 *et seq.*
———, Dutch Rhenish, iron permanent way of the, 121.
———, East Indian, Denham-Olpherts sleeper used on the, 37.
———, Ems and Wiesbaden, Hilf's system of iron permanent way on the, 7.
———, Great Western, employment of Macdonnell's iron permanent way on the, 3 *et seq.*
———, Hague and Scheveningen. *Vide* Tramway, 121.
———, Kreienzen and Holzminden, Daelen's iron permanent way on the, referred to, 6, 89.
———, London and North Western, Webb's steel sleeper used on the, 21 *et seq.*
———, London and South Western, standard permanent way of the, 77.
———, North Eastern, Wood's iron permanent way on the, 18 *et seq.*
———, North Western of Austria, Hohenegger's iron permanent way on the, 10.
———, Northern of France, failure of the Vautherin sleepers tried on the, 68.
———, Oude and Rohilkund, embossed steel sleepers used on the, 40 *et seq.*
———, Paris, Lyons and Mediterranean, use of iron sleepers on the, 68 *et seq.*
———, Prussian Rhenish, employment of iron permanent way on the, referred to, 9, 16.
———, St. Gothard, the rolling stock of the, 467.
———, South Eastern of France, stone block sleepers used on the, 82.
———, Southern of France, permanent way of the, type of wooden sleepers and their price, 84.
Railways, Swedish Government, non-use of metallic sleepers on the, owing to the cheapness of wood, 71.
———, Swiss, maintenance of the permanent way of the, 56.
———, local traffic on, the working of, 473.
———, measurement of speed on, 466.
Rainfall at Boston, Lincolnshire, 229 *et seq.*

Digitized by Google

Rankine, W. J. M., his formula for the weight of a framed girder, 335.
Raper, J. C. D., admitted student, 199.
Rapier, R. C., remarks as to metallic permanent way, 48.—Ditto as to the conditions under which iron sleepers might be generally adopted, 48.—Ditto as to closing the ends of iron trough-sleepers, 49.
Ravenhill, T., admitted student, 199.
Rawlinson, R., C.B., remarks as to metallic permanent way, 27.—Ditto as to the advantages of an elastic foundation for permanent way, 58.—Ditto as to the failure of rigid sleepers on the early railways, 58.—Ditto as to the conservancy of rivers, 291.—Ditto as to the piecemeal legislation in the case of the Fen drainages, 291.—Ditto as to the functions of rivers in civilized countries, 291.—Ditto as to the impracticability of impounding reservoirs, 292.—Ditto as to the iver Clyde, 292.—Ditto as to the unceasing dredging necessary to maintain the Suez Canal, 292.—Ditto as to the decay of English rivers, 293.—Ditto as to the reports of himself and Mr. J. T. Harrison, on the Thames, the Lee, and the Aire and Calder, 293.—Ditto as to a centralised jurisdiction for English rivers, with a Cabinet minister at its head, 294.
Rawtenstall, rainfall at, 236.
Read, C. S., opinion of, as to pipe drainage and steam cultivation in respect to floods, 273, 296.
Reaping machines, experiments on the work done by, 512.
Recoil. "Forces and Strains of Recoil considered with reference to the Elastic Field Gun-Carriage," 122.
Redman, J. B., remarks as to the conservancy of rivers, 253.—Ditto as to the tides in the Thames, 253.—Ditto as to Sir C. Vermuyden's operations in the Fens, 253.—Ditto as to the tidal oscillation in the Wash, 254.
Reid, H. D. A., elected associate member, 201.
——, R. C., remarks as to the conservancy of rivers, 316.—Ditto as to a flood of the Tweed in March, 1881, 316.
Reitz, F. H., apparatus for measurement of base lines, 421.
Reservoir, Corbet, of the Bann Reservoir Company, 317.
————, Lough Island Reavy, of the Bann Reservoir Company, 317 *et seq.*
Reservoirs, compensation, for preventing floods, 244 *et seq.*
Rich, W. E., remarks as to the elastic field gun-carriage, 159.—Ditto as to the Moncrieff hydro-pneumatic carriage, 159.—Ditto as to the hydraulic buffer of Sir Andrew Clarke, 159.
Righi, A., on a case of permanent polarity in steel opposed to that of the magnetising coil, 538.
River Bann, floods of the, and the Bann reservoirs, 317 *et seq.*
—— Cherwell, effects of floods in the upper part of the, 289.
—— Clyde, exceptional conditions of, as to its conservancy, 299.
—— Danube, ancient course of the, at Vienna, 282.
—— Erne improvement works, account of the, 314.
—— Etherow, in Longdendale, flood of the, in 1852, 255.
—— Gala, flood of the, in March, 1881, 316.
—— Hull, account of the, 258.
—— Humbew, and the outfall of the Hull, 258.
—— Irwell, floods of the, 233 *et seq.*
—— Lee, report of R. Rawlinson, C.B., and J. T. Harrison on the, referred to, 293.
—— Marne, flood of the, in 1877, 288.
—— Medlock, flood of the, in 1833, 255.

Digitized by Google

River Mersey, area of the watershed of the, 235 *et seq.*
—— Muddock, effect of, in increasing the floods of the Bann, 318.
—— Nene, regimen of the, 201 *et seq.*
—— Nidd, great flood of the, in 1868, 290.
—— Olona, conservancy, of the, 447.
—— Ouse, regimen of the, 201 *et seq.*
—— Seine, flood of the, in 1877, 288.
—— Slea, conversion of, into a navigation, referred to, 215.
—— South Witham. *Vide* River Witham.
—— Sudbury, Massachusetts, the flow of the, for the years 1875–79, 448.
—— Thames, tides of the, phenomenon observed in, 253.
—— Theiss, flood of the, at Szegedin in 1879, 303.
—— Tiber, plans proposed for the regulation of, and for the prevention of, floods in Rome, 271, 324 *et seq.*
—— Tweed, flood of the, in March, 1881, 306.
—— Tyne, beneficial effects of dredging the bed of the, 282.
—— Weaver, floods in the, and their influence on the navigation interests, 329.
—— Welland, regimen of the, 201 *et seq.*
—— Wharfe, flood of the, in December, 1869, 290.
—— Witham, regimen of the, 201 *et seq.*
Rivers. "The Conservancy of Rivers: the Eastern Midland District of England," 201.—Legislation on floods a proximate necessity, 201.—General characteristics of the eastern midlands of England, 202.—Drainage operations of the early adventurers, 203.—The Witham, 205.—The Welland, 207.—The Nene, 209.—The Ouse, 212.—Inland navigation, 214.—Cause of floods, 217.—Remedy, 219.—Regulation and storage of the water, 224.—Conservancy, 225.—Appendix I. Basins of the Witham, Welland, Nene, and Ouse rivers, 228.—II. Rainfall at Boston, 229.—III. Table showing effect of rain in causing floods in the Witham, 231.—IV. Particulars of the watersheds of the rivers Witham, Welland, Nene, and Ouse, 233.
———. "The Conservancy of Rivers: the Valley of the Irwell," 233.—Definition of the term "river conservancy," 233.—Alleged increased tendency towards flooding observable in England of late years, 233.—Physical characteristics of the Irwell, 234.—Flood of 16th November, 1866, 237.—Recommendation of the Rivers Pollution Commission in respect to the Irwell, 237.—Encroachments on the river channel by riparian occupiers, 238.—Effects of weirs at Douglas Green and Throstle Nest, 239.—Probable causes which have induced the present tendency to flooding in the Irwell, 240.—Reports of Mr. Hawksley, Mr. Bateman, and Mr. Cawley, 241.—Remedies suggested, 243.—Constitution and election of authorities entrusted with river conservancy, 244.—Rights of private occupiers, 245.—River conservancy on the Continent of Europe, 246.—Legislation on rivers, 248.
——— Aire and Calder, report of R. Rawlinson, C.B., and J. T. Harrison on the, referred to, 293.
"Rivers Conservancy and Floods Prevention Bill," the provisions of the, 264.
Rivers, German, observations of the water level of, undertaken with the permission of the Minister of Public Works, 305.
——— having a considerable fall, and with beds liable to scour, method of improving, 445.
———, Indian, conservancy of, by the Government, 323.

Digitized by Google

"Rivers Pollution Commission," inquiry of, into the state of the Irwell, referred to, 237.
Roads, underground, in colleries, timbering, 503.
Rochdale, rainfall at, 236.
Roelker, C. R., experiments on the strength of wrought iron and steel at high temperatures, 437.
Rolling stock of the St. Gothard Railway, the, 467.
Roofs. "The Weights of Framed Girders and Roofs," 331.—Determination of the limiting spans deduced from various formulæ for the approximate weight of a girder, 331.—Anderson's formula, 332.—Unwin's formula, 333.—Baker's formula, 333.—Stoney's formula, 334.—Rankine's formula, 335.—Mode of applying the foregoing for large and small structures, 336.
Roper, J. S., admitted student, 199.
Ropes, wire, 506.—Steel wire for, 509.
Ross, J., admitted student, 199.
Rougier, —, Remarks as to metallic permanent way, 85.—Ditto as to the cost being at present in favour of wood for sleepers in France, 85.—Ditto as to the weak points of iron sleepers similar to those of the Vautherin type, 85.
Rumball, A. B., admitted student, 199.
Rumble, W. C. S., admitted student, 199.
Rumsby, E. J., elected associate member, 201.
Russell, H. C., note on a new method of printing barometer- and other curves, 521.
———, J., elected member, 200.
Rymer-Jones, A. M., memoir of, 407.

Sacré, E. A., memoir of, 419.
Sandbanks and sandhills, on the formation of, and on the construction of harbours on sandy coasts, 455.
Sandberg, C. P., remarks as to metallic permanent way, 85.—Ditto as to the iron sleepers introduced on some German railways, 85.—Ditto as to wood being a preferable material for sleepers so long as it is as cheap as iron, 86.—Ditto as to timber being still plentiful in countries where the great cold rendered the adoption of iron for sleepers inadvisable, 86.
Sande-Bakhuyzen, Professor H. G. van de, changes in length of wooden levelling staves, 421.
Salford, rainfall at, 236.—Corporation of, and floods in the Irwell, 237 *et seq.*
Sarran, —, borings for coal in the south of France, 499.
Scharnweber's electric lamp, 536.
Scheffler, H., his system of iron permanent way used on the Brunswick railway, referred to, 6.
———, remarks as to metallic permanent way, 87.—Ditto as to the trials of iron sleepers on the Brunswick railway in 1864, 87.—Ditto as to the oaken sleeper way still retained on the Brunswick railway, 92.—Ditto as to the "Hörster Union" sleeper, 92.—Ditto as to the comparative deflection of metal and wood sleepers under the passage of a train, 92.—Ditto as to the value of any system of sleepers depending on the amount of bearing surface afforded, 93.—Ditto as to the conditions of cost which would govern the general adoption of iron permanent way, 93.—Ditto as to some errors in Mr. Wood's Paper, 97.
Schlink, H., on the future technical training of smelters, 540.
Schwedler, J. W., remarks as to metallic permanent way, 95.—Ditto as to the theoretical conditions governing the suitability of any system of permanent way,

Digitized by Google

95.—Ditto as to the Barlow system, 99.—Ditto as to Hilf's system, 100.—Ditto as to Haarmann's system, 100.—Ditto as to the action of the vehicles on the ballast under transverse and longitudinal sleepers, 102.—Ditto as to the most suitable form of fastening for transverse sleepers, 113.—Ditto as to the influence of shape in retaining the ballast, 114.—Ditto as to the importance of good fishing, 117.

Scorgie, N., admitted student, 199.

Screw-propeller, application of the, to aerial navigation, 369 *et seq.*

Sea-water, effect of, on the strength of Portland cement, 349 *et seq.*

Sebert, Col., experiments of, on the velocity of projectiles and the recoil of guns, 175 *et seq.*

Shakespear, Col. J. D., remarks as to the elastic field gun-carriage, 143.—Ditto as to the requisites of a field gun-carriage being strength and solidity of construction rather than elaborate mechanical appliances for preventing recoil, 143.

Shaw, H. R., remarks as to metallic permanent way, 49.—Ditto as to the wrought-iron sleepers for colliery lines introduced by Mr. Legrand, and their suitability for Indian and colonial railways, 49.—Ditto as to the action of the Indian Government in respect to persons tendering for iron sleepers, 51.—Ditto as to the mode of renewing Legrand's sleepers, 60.

Shelford, W., remarks as to the conservancy of rivers, 271.—Ditto as to the effect of the admission of tidal water into the mouth of a river, 271.—Ditto as to the river Nene, 271.—Ditto as to the formation of bars, 271.—Ditto as to the river Tiber, 271.—Ditto as to the benefits of embankments in lowering the low-water level, 273.

Siemens, Dr. C. W., remarks as to metallic permanent way, 27.—Ditto as to the probable supersession of iron by steel as a material for sleepers, 27.—Ditto as to the elastic field gun-carriage, 148.—Ditto as to the hydraulic buffer, 149.—Ditto as to the term "elastic gun-carriage," 149.—Ditto as to the charge of complication brought against the new carriage being unfoun ed, 149.

Slate, J., memoir of, 408.

Sleepers, wooden, cost of in England, 26; France, 84; Germany, 93; Sweden, 71, 86.

Sluices in the Fen rivers, 201 *et seq.*

Sluicing basin at Honfleur. *Vide* Basin.

Smith, H, B., elected associate member, 201.

——, R., jun., admitted student, 199.

——, Dr. R. Angus, his anti-corrosive composition used for metallic sleepers, 42.

Smyth, J., jun., remarks as to the conservancy of rivers, 317.—Ditto as to the advisability of a general Conservancy Board for the control of rivers, 317.—Ditto as to the history of the Bann reservoirs, 317.—Ditto as to the recommendation of Sir W. Fairbairn to construct three impounding reservoirs, 317.—Ditto as to the construction of the Corbet reservoir, 317.—Ditto ditto Lough Island Reavy reservoir, 319.—Ditto as to the effect of the reservoirs, 320.—Ditto as to the opinions of various engineers consulted on the question of floods of the river Bann, 320.—Ditto as to the various plans proposed for their abatement, 322.

Smythe, A. J. Hamilton. *Vide* Hamilton Smythe.

Solly, H. le G., elected associate member, 201.

Speed-meter, magnetic, 540.

—— on railways, measurement of 466.

Spring, F. J. E., elected associate member, 201.

Stamps, American, for gold and silver ores, 497.

Digitized by Google

Staves, levelling-, wooden, changes in length of, 421.
Steel, annealing of, 492.
——, permanent polarity in, case of, 538.
——, different qualities of, as regards magnetism and its permanency, 520.—*Vide* also Tetmajer.
——, strength of at high temperatures, experiments on the, 437.
—— wire for ropes, 509.
——, "Steel for Tires and Axles," 353.
—— and iron, on a producer's classification of, 484.
—— determination of the quality of, 438.
Stoney, B. B., his formula for the weight of a framed girder, 334.
Suquet, M. *Vide* Demoly.
Swedish Government railways. *Vide* Railways.
Swiss railways. *Vide* Railways.
Symons, G. J., remarks as to the conservancy of rivers, 273.—Ditto as to early bridges not being built to pass off floods, 273.—Ditto as to the evils of divided jurisdiction in river conservancy, 273.—Ditto as to the effect of drainage on floods, 273.—Ditto as to the alleged increase of rainfall in England of late years, 273.—Ditto as to the Lancashire flood of November 1866, 274.

Talman, J. J., elected associate member, 201.
Tanner, T. L., memoir of, 410.
Taylor, R. C., admitted student, 199.
Tebbutt, C., remarks as to the conservancy of rivers, 274.—Ditto as to the admission of the tidal wave into the mouths of rivers, 274.—Ditto as to the sluices on the Fen rivers, 275.
Technical education. *Vide* Training.
Telegraph system, Imperial German, the underground conducting network of the, 537.
Telegraphy, application of the radiophone to, 537.
Telephone, use of the, as a means of communication during the training of infantry in shooting, 541.
Tetmajer, Prof. L., determination of the quality of wrought iron and steel, 438.
Thermometers, electrical, for observing temperature at a distance, 540.
Thomas, F. S., admitted student, 199.
Thomson, T., admitted student, 199.
Thornycroft, J. J., reduction in the weight of propelling apparatus, inaugurated by, referred to, 369.
Thursfield, W. E., elected member, 200.
Thurston, Prof. R. H., on the effect of prolonged stress upon the strength and elasticity of pine timber, 430.
Tides in the Thames and the Wash, phenomena observed in, 253, 254.
Timber, pine, on the effect of prolonged stress upon the strength and elasticity of, 430.
Timbering underground roads in collieries, 503.
Tires, steel for, 353.
Tommasi, D., action of cold on the voltaic arc, 523.
Tone, J. F., memoir of, 399.
Torode, A., admitted student, 199.
Torsion of prismatic bodies, experimental proofs of some new formulæ for the, 432.
Towle, H. E., memoir of, 411.

Digitized by Google

Traffic, local, on railways, the working of, 473.
Training, technical, of smelters, on the future, 542.
Tramway, steam, Hague and Scheveningen, use of Haarmann's iron permanent way, on the, referred to, 127.
Tramways, Dundee. "Extension of the Dundee Street Tramways, 338.—Tramway system of Dundee, 338.—Gowan's rails used in the extensions, 338.—Concrete foundations, 339.—Mackison's system of iron permanent way for tramways, 340.—Comparative cost of Gowan's, heavy, and Mackison's system. 342.—Results of the Dundee tramways, 343.
———, Oxford. "The Oxford and District Tramways," 345.—Route of the tramways, 345.—Rail used, 346.—Foundation, 347.—Cost, 348.
Triangulation of Algeria. On the extension of the Paris meridian to the Sahara, 422.
Trouvé, G., on the manufacture of magnets, 538.
Tubes, chains of, forming electric condensers, 529.
Tulloch, F. H., elected associate member, 201.
Tunnel through Salford, proposed, to carry off the flood-waters of the Irwell, 242 *et seq.*
Tunnels, Alpine, the ventilation and cooling of, 442.
Tyler, J. F., elected member, 200.

Underground conducting network of the Imperial German telegraph system, 537.
Units adopted by the Congress of Electricians, 522.
Unwin, H., remarks as to the conservancy of rivers, 323.—Ditto as to the mode now followed by the Government of India in dealing with the rivers of Bengal and Orissa, 323.
———, Prof. W. C., remarks on the elastic field gun-carriage, 147.—Ditto as to the formula $W V = w v$, 147.—Ditto as to the effect of the friction of the earth and of the forward momentum of a mass of air on the recoil of the carriage, 148.—His formula for the weight of a framed girder, 333.

Vautherin, J., his system of metallic cross sleeper for railways, 1 *et seq.*—Remarks as to ditto, 120.—Ditto as to the cause of the non-success of the trials of his sleeper on the Grand Central Railway of Belgium, 120.—Ditto as to the Vautherin sleepers on the Algerian railways, 120.—Ditto as to recent modifications of the original type, 120.
Vavasseur, J., his hydraulic gun-carriage referred to, 178.
Velocimeter of Colonel Sebert, description of the, 176.
Ventilation and cooling of Alpine tunnels, 442.
Verdon, A. L. R., admitted student, 199.
Vermuyden, Sir C., his plans for draining the Fens and preventing flooding, 203 *et seq.*
Vernon-Harcourt, L. F., remarks as to the conservancy of rivers, 283.—Ditto as to the expediency of dealing with a river basin as a whole, 283.—Ditto as to the river Witham, 283.—Ditto as to the effect of tidal flow, 284.—Ditto as to the causes of flooding in the Upper Thames, 285.—Ditto as to the replacement of existing weirs by movable ones, 287.—Ditto as to the change of inclination of river beds towards their mouth, 287.—Ditto as to the classification of rivers, 287.—Ditto as to the system of flood warnings on the Seine and the Marne. 288.—Ditto as to floods in the Cherwell, 289.
Verschoyle, J. K. E., admitted student, 199.

Digitized by Google

Vescovali, A., remarks as to the conservancy of rivers, 324.—Ditto as to the various proposals for the regulation of the Tiber, and prevention of floods in Rome, 324.
Voltaic arc. *Vide* Arc.

Walker, B., remarks as to the elastic field gun-carriage, 157.—Ditto as to Dr. Siemens's connection with the hydraulic buffer, 158.—Ditto as to a prejudicial vibratory motion easily set up in hydraulic pressure gauges, 158.
Wallace, J., elected associate member, 201.
Walsh, W. H. M., admitted student, 199.
Waring, H. F., admitted student, 199.
Wash, the, and the regimen of the Fen rivers, 201 *et seq.*
Water-gas. *Vide* Gas.
Waves, magnetic, propagation of, in soft iron, 519.
Webb, F. W., his steel railway sleeper referred to, 21 *et seq.*
Weir, Douglas Green, on the Irwell, 239.
——, Port-à-l'Anglais, France, contrivance for working the needles of the new overfall at, 453.
——, Throstle Nest, on the Irwell, 239.
Weirs, effects of, on river floods, 240 *et seq.*
Wells, J. W., elected member, 200.
——, L. B., remarks as to the conservancy of rivers, 327.—Ditto as to the impossibility of wholly preventing floods to low-lying land, 327.—Ditto as to the Prevention of Floods Bill of 1881, 328.—Ditto as to floods in the river Weaver, 329.—Ditto as to the probability that the inland navigation interests would suffer from a too rigid exercise of the powers proposed to be granted to the Local Government Board, 330.
Wheeler, W. H., "The Conservancy of Rivers: the Eastern Midland District of England," 201.—Remarks as to ditto, 249.—Ditto as to the improvements already carried out in the Fen rivers, 249.—Ditto as to the throttle in the Nene, 294.—Ditto as to the formation of bars, 294.—Ditto as to the effect of admitting the tide, 295.—Ditto as to sluices, 296.—Ditto as to the opinion of Mr. C. S. Read on pipe drainage in respect of floods, 296.
White, F. T., remarks as to the conservancy of rivers, 330.—Ditto as to the principal source of the river Witham, 330.
——, Rev. J., remarks as to the elastic field gun-carriage, 149.—Ditto as to the effect of the air upon shot and gun, 150.—Ditto as to the Moncrieff gun-carriage, 150.—Ditto as to some confusion existing in the terms "statical" and "dynamical" force, 151.
Whiting, H., the propagation of magnetic waves in soft iron, 519.
Wicksteed, J. H., memoir of, 413.
Williams, E. B., memoir of, 415.
——, R. Price, remarks as to metallic permanent way, 46.—Ditto as to Webb's steel sleepers, 46.—Ditto as to a comparison between the cost of iron, steel, and wooden sleepers, 47.
Willis, Professor, Galton, Captain D., and James, Sir H., experiments of, on the flexure of rails, referred to, 52.
Wilson, M., admitted student, 199.
Winkler, Dr. E., his system of iron permanent way, referred to, 11.
Wire ropes, 506, 509.
Wisbech, town of, and improvements of the Nene, 226.

Digitized by Google

Wood, C., "Iron Permanent Way," 1.—Remarks as to ditto, 62.—Ditto as to Bergeron's inverted trough system, 62.—Ditto as to Legrand's sleepers, 62.—Ditto as to the advantages of long sleepers in providing sufficient bearing, 63.—Ditto as to the question of closed ends for metallic sleepers, 63.—Ditto as to de Bergue's plate sleeper used in Spain, 64.—Ditto as to the causes of the fracture of some of his own sleepers on the North Eastern railway, 65.—Ditto as to the failure of systems of mixed iron and wooden sleepers, 65.—Ditto as to corrosion, 65.—Ditto as to the use of worn Barlow rails for structural purposes, 65.—Ditto as to the simplicity of his sleeper and fastening, 66.—Ditto as to the cost of different systems of metallic permanent way, 67.

Woods, R. J., elected associate member, 201.

Wright, R., remarks as to metallic permanent way, 120.—Ditto as to the iron sleepers in use on the Dutch Rhenish Railway, 121.—Ditto as to Haarmann's longitudinal system on the Hague and Scheveningen steam tramway, 121.

Zinc smelting, machine-made muffles for, 496.

END OF VOL. LXVII.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

OCT 2 9 1935

Digitized by Google

Digitized by Google